NH

PREHISTORIC MAN. — From the Cave of Mentone. — Pages 575, 577.

MANUAL

OF

GEOLOGY:

TREATING OF THE PRINCIPLES OF THE SCIENCE

WITH SPECIAL REFERENCE TO

AMERICAN GEOLOGICAL HISTORY,

BY

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Nunquam aliud natura aliud sapientia dicet. — Juv.
Licet jam oculis quodammodo contemplari pulchritudinem rerum earum, quas divina providentia dicimus constitutas. — Cic.

ILLUSTRATED BY OVER ELEVEN HUNDRED AND FIFTY FIGURES IN THE TEXT, TWELVE PLATES, AND A CHART OF THE WORLD.

THIRD EDITION.

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PREFACE.

In preparing this Manual for a third edition, the section on Kinds of Rocks has been changed throughout; the Dynamical part has been mostly rewritten, and has become enlarged one half, besides receiving brief bibliographic lists illustrating the history of its more important doctrines, and many additions to its figures; and the Historical Geology, while only partially revised, has been greatly modified with reference to Green Mountain Geology, American fossil Vertebrates, and the Glacial and Champlain periods of the Quaternary. In addition, the work is now supplemented, through the gift of Professor Marsh, by twelve plates of figures illustrating species of Reptiles, Birds, and Mammals, from the Jurassic, Cretaceous, and Tertiary formations west of the Mississippi.

The general plan of the Manual remains unchanged. Those preferring the more common method of arrangement can readily make the instruction in Dynamics to follow directly the descriptive chapter on the Condition, Structure, and Arrangement of Stratified and Unstratified rocks, under Lithological Geology.

James D. Dana.

New Haven, Conn., *November* 1, 1879.

FROM THE PREFACE TO THE SECOND EDITION.

Two reasons have led the author to give this Manual its American character: first, a desire to adapt it to the wants of American students; and, secondly, a belief that American Geological History, on account of the peculiar simplicity and unity of the system of progress, affords the best basis for a text-book of the science. North America stands alone in the ocean, a simple isolated individual continent, even South America lying to the eastward of its meridians; and, consequently, the laws and agencies of progress have been undisturbed by conflicting conditions and movements in other lands. The author has, therefore, written out North American Geology by itself, and

drawn the chief illustrations of continental development from its records. Facts from other continents, however, have been freely added, because required both to give completeness to the treatise, and to exhibit the comprehensiveness of geological principles. The aim has been to present for study the successive phases in the HISTORY of the Earth; that is, of its Continents, its Seas, its Climates, its Life, and of all its various characteristics, and not a mere series of facts about rocks and their dead fossils.

The author has endeavored to bring the volume into as small a compass as consistent with a proper exhibition of the science; and, if some find its pages too numerous, he feels confident that quite as many would prefer greater fullness. The details introduced have seemed to be necessary, in order that the march of events should be appreciated. At the same time, the work has been adapted to the general reader and literary student, by the printing of the scientific details in finer type. The convenience of a literary class has been further provided for by adding to the Appendix a brief synopsis of the part in coarser type, in which each head is made to present a subject, or question, for special attention. And, as many may not be familiar with the science of Zoölogy, a review of the classification of animals, with numerous figures, has been inserted as an introduction to the Historical part of the Manual.

The illustrations of American Paleozoic life have been largely copied from the reports of Professor HALL. A few of the Paleozoic figures, and many of those of later periods, are from original drawings, made by Mr. F. B. MEEK, to whose artistic skill and paleontological science the work throughout is greatly indebted. The drawings were nearly all made on the wood, for engraving, by Mr. Meek; and the paleontological pages have had the benefit of his revision. The name of the engraver, LOCKWOOD SANFORD, of New Haven, also deserves mention in this place.

The preceding paragraphs have been taken, with little change, from the Preface to the first edition of this work, dated November 1st, 1862. They remain true for this new edition. Yet the work has been for the most part rewritten, and is greatly enlarged. The changes have been made necessary, both by the progress in geological investigation over the United States and British America, and by the general advance of geological science.

During the interval since 1862, surveys have been going forward, and have been partly or wholly completed, in California, the Territories over the summit and slopes of the Rocky Mountains, the States of Minnesota, Iowa, Missouri, Louisiana, Tennessee, Illinois, Indiana,

Michigan, Ohio, North Carolina, and New Hampshire, and the Provinces of Canada, New Brunswick, Nova Scotia, and Newfoundland. These surveys have greatly extended our knowledge of American rocks and mineral products, besides affording aid toward a deeper insight into principles, and a clearer comprehension of the system that pervades the earth's structure. Besides all this, large contributions to paleontology have been made by some of the Reports, and most prominently by the new volume of the New York series, by JAMES HALL; the volumes of the Illinois Survey, by MEEK, WORTHEN, NEWBERRY, and LESQUEREUX; of the Ohio Survey, by NEWBERRY and MEEK; of the California Survey, under J. D. WHITNEY, by MEEK and GABB; of the Survey of the Territories, under F. V. HAYDEN, by MEEK, COPE, LEIDY, and LESQUEREUX; and of Canada, under Sir WM. E. LOGAN, by BILLINGS, DAWSON, and HALL. Various important memoirs also have appeared in the scientific journals and in the publications of scientific societies and academies, and some have been issued as independent works.

Since the year 1862, through SCUDDER, we have our first knowledge of the Insect-life of the Devonian; through LEIDY, COPE, and MARSH, we have seen the meagre list of American Cretaceous Reptiles enlarged, until it exceeds that from all the world besides; and through the same geologists, not only has the Mammalian fauna of the American Miocene received additions of many species, but the stranger fauna of the Rocky Mountain Eocene has been first made known; through MARSH, also, the first American Cretaceous Birds have been named, and the announcement has come of a Bird with teeth in sockets, like some of the higher Reptiles. In addition, the labors, among Invertebrates, of HALL, MEEK, BILLINGS, and others; among Fishes, of NEWBERRY; among fossil Plants, of LESQUEREUX and DAWSON, have greatly advanced these departments of American paleontology.

The discoveries abroad, also, have been many and important, though of less marked character than the American, because the accessible field had already been well explored. Large additions have been made to the history of prehistoric Man; and the frontispiece of this volume, — engraved, by Mr. JOHN KARST of New York, from the photograph accompanying the memoir of E. RIVIÈRE, — representing a skeleton of an inhabitant of Southern Europe in the Stone age, just as it lay after being uncovered from the stalagmite of a cavern, exemplifies one of the classes of facts which have been elucidated. Besides, much new light has been thrown on the successional relations of species, and also on the right methods of interpreting geological records.

In the preparation of this edition, I am largely indebted to many scientific friends: in the first place, to all workers in the department, through the land, whose published results have made the edition a necessity, and from whose works I have freely taken facts and conclusions, with due acknowledgment; also, for personal aid, to the able paleontologist, F. B. MEEK, to whom the country owes a world of gratitude for his labors; to O. C. MARSH, for facts connected with the Vertebrate life of the American Cretaceous and Tertiary; to A. H. WORTHEN, Director of the Geological Survey of Illinois, from whom the volume has received several of its illustrations; to L. LESQUEREUX, for information with regard to fossil plants; to JAMES HALL, the eminent paleontologist of New York; to J. S. NEWBERRY, Chief Geologist of the State of Ohio; to A. WINCHELL, formerly State Geologist of Michigan, and now Chancellor of the Syracuse University; to G. K. GILBERT, Geologist of the Explorations under G. M. WHEELER, First Lieutenant of Engineers, U. S. A.; to J. COLLETT, of the Indiana Geological Survey; to J. KNAPP, of Louisville, Kentucky; to G. C. BROADHEAD, State Geologist of Missouri; to J. W. DAWSON, Principal of McGill University, Montreal; to E. BILLINGS, of the Canadian Geological Survey, and one of the best workers among fossils on the continent; to S. W. JOHNSON, Professor of Agricultural and Analytical Chemistry, for information on chemical subjects; to the Zoölogist, A. E. VERRILL, for the revision of the zoölogical pages; to F. V. HAYDEN, Geologist in charge of the "Geological Survey of the Territories," for information pertaining to the Geysers and the geological structure of the Rocky Mountain region; and, through Dr. Hayden, to W. H. HOLMES, his artist, for drawings of geological scenes in the mountains; to JAMES T. GARDNER, Geographer in Surveys of the Territories, for facts with regard to the topographical features of the summit region and the western slope of the Rocky Mountains; and to G. W. HAWES, assistant in the Sheffield Scientific School, for analyses of plants, bearing on the question of the origin of coal.

To F. H. BRADLEY, I am under still greater obligations. For the work, besides having had the benefit of his careful and untiring labor in the revision of the proofs, has profited in various parts by his extensive knowledge of American Geology, rendered thorough and critical by personal investigations in several of the States and Territories.

NEW HAVEN, CONN., *March* 1, 1874.

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INTRODUCTION.

PART IV. — Dynamical Geology.

ABBREVIATIONS.

Ag.—L. Agassiz.
B.—E. Billings.
Barr.—J. Barrande.
Beyr.—E. Beyrich.
Blum.—J. F. Blumenbach.
Blv.—D. de Blainville.
Br.—H. G. Bronn.
Brngt.—Brongniart.
Brod.—Broderip.
Brug.—Bruguiere.
Brünn.—Brünnich.
Bu.—L. von Buch.
Buckm.—Buckman.
Chemn.—Chemnitz.
Con.—T. A. Conrad.
Couth.—J. P. Couthuoy.
Cpr.—P. P. Carpenter.
Cuv.—Cuvier.
D.—J. D. Dana.
Dalm.—J. W. Dalman.
Dav.—T. Davidson.
Defr.—Defrance.
Desh.—G. P. Deshayes.
Dn.—J. W. Dawson.
D'Orb.—Alcide d'Orbigny.
E. & H.—Edwards & Haime.
Eg.—Ph. Grey Egerton.
Ehr.—Ch. G. Ehrenberg.
Eich.—E. Eichwald.
Emmr.—H. F. Emmrich.
Fabr.—Fabricius.
Falc.—H. Falconer.
Flem.—J. Fleming.
Fer.—Ferussac.
G. & H.—Gabb & Horn.
Gein.—Geinitz.
Gld.—Gould.
Gm.—Gmelin.
Göpp.—H. R. Göppert.
Goldb.—Golderberg.
Goldf.—Goldfuss.
H.—J. Hall.
H. & M.—Hall & Meek.
Hald.—S. S. Haldeman.
Hising.—W. Hisinger.
Hk.—E. Hitchcock.
Hux.—T. H. Huxley.
Jäg.—G. F. Jäger.
Kg.—W. King.
Kon.—L. de Koninck.
L.—J. Leidy.
L. & C.—Lyon & Casseday.
L. & H.—Lindley & Hutton.
L. & M.—Lycett & Morriss.
Lam.—Lamarck.
Linn.—Linnæus.
Lmx.—Lamouroux.
Lsqx.—L. Lesquereux.
Lyc.—Lycett.
M.—F. B. Meek.
Mant.—G. Mantell.
Mart.—Martin.
Mg.—Montgomery.
Mey.—H. von Meyer.
Mh.—O. C. Marsh.
Montf.—Denys de Montfort.
Morr.—Morris.
Mort.—S. G. Morton.
Mü.—Gr. zu Münster.
Müll.—Müller.
Murch.—R. I. Murchison.
N. & P.—Norwood & Pratten.
N. & W.—Newberry & Worthen.
Newb.—J. S. Newberry.
O. & N.—Owen & Norwood.
Ow.—R. Owen (London).
Pack.—A. S. Packard.
Park.—J. Parkinson.
Phill.—J. Phillips.
Plien.—T. Plieninger.
Portl.—J. E. Portlock.
Qu.—Fr. A. Quenstedt.
R.—F. Römer.
Rém.—A. Rémond.

S.—J. W. Salter.
Saff.—J. M. Safford.
Sc.—S. H. Scudder.
Schafh.—Schafhäutl.
Schlot.—E. F. von Schlotheim.
Schp.—W. P. Schimper.
Sedg.—A. Sedgwick.
Shum.—B. F. Shumard.
Sow.—Sowerby.
St.—Stokes.
Sternb.—K. von Sternberg.
Stp.—W. Stimpson.
Stutch.—Stutchbury.
Suck.—Suckow.
T. & Hs.—Tuomey & Holmes.
Ung.—Unger.
Van.—Vanuxem.
Vern.—E. de Verneuil.
Woodw.—J. Wooaward.
Wiss.—Wissmann.
Wulf.—Wulfen.
Zimm.—Zimmermann.

INTRODUCTION.

Kingdoms of nature. — SCIENCE, in her survey of the earth, has recognized three kingdoms of nature, — the animal, the vegetable, and the inorganic; or, naming them from the forms characteristic of each, the ANIMAL KINGDOM, the PLANT KINGDOM, and the CRYSTAL KINGDOM. An individual in either kingdom has its systematic mode of formation or growth.

The plant or animal, (1) endowed with life, (2) commences from a germ, (3) grows by means of imbibed nutriment, and (4) passes through a series of changes and gradual development to the adult state, when (5) it evolves new seeds or germs, and (6) afterward continues on to death and dissolution.

It has, hence, its cycle of growth and reproduction, and cycle follows cycle in indefinite continuance.

The crystal is (1) a lifeless object, and has a simpler history; it (2) begins in a nucleal molecule or particle; (3) it enlarges by external addition or accretion alone; and (4) there is, hence, no proper development, as the crystal is perfect, however minute; (5) it ends in simply existing, and not in reproducing; and, (6) being lifeless, there is no proper death or necessary dissolution.

Such are the individualities in the great kingdoms of nature displayed upon the earth.

But the earth also, according to Geology, has been brought to its present condition through a series of changes or progressive formations, and from a state as utterly featureless as a germ. Moreover, like any plant or animal, it has its special systems of interior and exterior structure, and of interior and exterior conditions, movements and changes; and, although Infinite Mind has guided all events toward the great end, — a world for mind, — the earth has, under this guidance and appointed law, passed through a regular course of history or growth. Having, therefore, as a sphere, its comprehensive system of growth, it is a unit or individuality, not, indeed, in either of the three kingdoms of nature which have been mentioned, but in a higher, — a WORLD KINGDOM. Every sphere in space must have had a re-

lated system of growth, and all are, in fact, individualities in this Kingdom of Worlds.

Geology treats of the earth in this grand relation. It is as much removed from Mineralogy as from Botany and Zoölogy. It uses all these departments; for the species under them are the objects which make up the earth and enter into geological history. The science of minerals is more immediately important to the geologist, because aggregations of minerals constitute rocks, or the plastic material in which the records of the past were made.

The earth, regarded as such an individuality in a world-kingdom, has not only its comprehensive system of growth, in which strata have been added to strata, continents and seas defined, mountains reared, and valleys, rivers, and plains formed, all in orderly plan, but also a system of currents in its oceans and atmosphere, — the earth's circulating-system; its equally world-wide system in the distribution of heat, light, moisture and magnetism, plants and animals; its system of secular variations (daily, annual, etc.) in its climate and all meteorological phenomena. In these characteristics the sphere before us is an individual, as much so as a crystal, or a tree; and, to arrive at any correct views on these subjects, the world must be regarded in this capacity. The distribution of man and nations, and of all productions that pertain to man's welfare, comes in under the same grand relation; for, in helping to carry forward man's progress as a race, the sphere is working out its final purpose.

There are, therefore,

Three departments of science, arising out of this individual capacity of the earth.

I. Geology, which treats of (1) the earth's structure, and (2) its system of development, — the last including (1) its progress in rocks, lands, seas, mountains, etc.; (2) its progress in all physical conditions, as heat, moisture, etc.; (3) its progress in life, or its vegetable and animal tribes.

II. Physiography, which begins where Geology ends, — that is, with the adult or finished earth, — and treats (1) of the earth's final surface-arrangements (as to its features, climates, magnetism, life, etc.); and (2) its system of physical movements or changes (as atmospheric and oceanic currents, and other secular variations in heat, moisture, magnetism, etc.).

III. The earth with reference to man (including ordinary Geography): (1) the distribution of races or nations, and of all productions or conditions bearing on the welfare of man or nations; and (2) the progressive changes of races and nations.

The first considers the structure and growth of the earth; the

second, its features and world-wide activities in its finished state; the third, the fulfillment of its purpose in man, for whose pupilage it was made.

Relation of the earth to the universence.— While recognizing the earth as a sphere in a world-kingdom, it is also important to observe that the earth holds a very subordinate position in the system of the heavens. It is one of the smaller satellites of the sun, — its size about 1-1,200,000th that of the sun. And the planetary system to which it belongs, although 3,000,000,000 of miles in radius, is but one among myriads, the nearest star 7,000 times farther off than Neptune. Thus it appears that the earth is a very small object in the universe. Hence we naturally conclude that it is a dependent part of the solar system; that, as a satellite of the sun, in conjunction with other planets, it could no more have existed before the sun, or our planetary system before the universe of which it is a part, than the hand before the body which it obediently attends.

Although thus diminutive, the laws of the earth are the laws of the universe. One of the fundamental laws of matter is gravitation; and this we trace not only through our planetary system, but among the fixed stars, and thus *know* that one law pervades the universe.

The rays of light which come in from the remote limits of space are a visible declaration of unity; for this light depends on molecular vibrations, — that is, the ultimate constitution and mode of action of matter; and, by the identity of its principles or laws, whatever its source, it proves the essential identity of the molecules of matter.

Meteoric stones are specimens of celestial bodies occasionally reaching us from the heavens. They exemplify the same chemical and crystallographic laws as the rocks of the earth, and have afforded no new element or principle of any kind.

The moon presents to the telescope a surface covered with the craters of volcanoes, having forms that are well illustrated by some of the earth's volcanoes, although of immense size. The principles exemplified on the earth are but repeated in her satellite.

Thus, from gravitation, light, meteorites, and the earth's satellite, we learn that there is oneness of law through space. The elements may differ in different systems, but it is a difference such as exists among known elements, and could give us no new fundamental laws. New crystalline forms might be found in the depths of space, but the laws of crystallography would be the same that are displayed before us among the crystals of the earth. A text-book on Crystallography, Physics, or Celestial Mechanics, printed in our printing-offices, would serve for the universe. The universe, if open throughout to our explorations, would vastly expand our knowledge, and science might have a more beautiful superstructure, but its basement-laws would be the same.

The earth, therefore, although but an atom in immensity, is immensity itself in its revelations of truth; and science, though gathered from one small sphere, is the deciphered law of all spheres.

It is well to have the mind deeply imbued with this thought, before entering upon the study of the earth. It gives grandeur to science and dignity to man, and will help the geologist to apprehend the loftier characteristics of the last of the geological ages.

Special aim of geology, and method of geological reasoning. — Geology is sometimes defined as the science of the structure of the earth. But the ideas of structure and *origin* of structure are inseparably connected, and in all geological investigations they go together. Geology had its very beginning and essence in the idea that rocks were made through secondary causes; and its great aim has ever been to study structure in order to comprehend the earth's history. The science, therefore, is a historical science. It finds strata of sandstone, clayey rocks, and limestone, lying above one another in many successions; and, observing them in their order, it assumes, not only that the sandstones were made of sand by some slow process, clayey rocks of clay, and so on, but that the strata were *successively* formed; that, therefore, they belong to *successive periods* in the earth's past; that, consequently, the *lowest* beds in a series were the *earliest* beds. It hence infers, further, that each rock indicates some facts respecting the condition of the sea or land at the time it was formed, one condition originating sand deposits, another clay deposits, another lime, — and, if the beds extend over thousands of square miles, that the several conditions prevailed uniformly to this same extent at least. The rocks are thus regarded as records of successive events in the history, — indeed, as actual historical records; and every new fact ascertained by a close study of their structure, be it but the occurrence of a pebble, or a seam of coal, or a bed of ore, or a crack, or any marking whatever, is an addition to the records, to be interpreted by careful study.

Thus every rock marks an epoch in the history; and groups of rocks, periods; and still larger groups, ages; and so the ages which reach through geological time are represented in order by the rocks that extend from the lowest to the uppermost of the series.

If, now, the great beds of rock, instead of lying in even horizontal layers, are much folded up, or lie inclined at various angles, or are broken and dislocated through hundreds or thousands of feet in depth, or are uplifted into mountains, they bear record of still other events in the great history; and should the geologist, by careful study, learn how the great disturbance or fracture was produced, or succeed in locating its time of occurrence among the epochs registered in the rocks, he would have interpreted the record, and added not only a fact

to the history, but also its full explanation. The history is, hence, a history of the upturnings of the earth's crust, as well as of its more quiet rock-making.

If, in addition, a fossil shell, or coral, or bone, or leaf, is found in one of the beds, it is a relic of some species that lived when that rock was forming; it belongs to that epoch in the world represented by the particular rock containing it, and tells of the life of that epoch; and, if numbers of such organic remains occur together, they enable us to people the seas or land, to our imagination, with the very life that belonged to the ancient epoch.

Moreover, as such fossils are common in a large number of the strata, from the lowest containing signs of life to the top, — that is, from the oldest beds to the most recent, — by studying out the characters of these remains in each, we are enabled to restore to our minds, to some extent, the population of all the epochs, as they follow one another in the long series. The strata are thus not simply records of moving seas, sands, clays, and pebbles, and disturbed or uplifted strata, but also of the living beings that have in succession occupied the land or waters. The history is a history of the life of the globe, as well as of its rock-formations; and the life-history is the great topic of Geology: it adds tenfold interest to the other records of the dead rocks.

These examples are sufficient to explain the basis and general bearing of geological history.

The method of interpreting the records rests upon the simple principle that rocks were made as they are now made, and that life lived in olden time as it now lives; and, further, the mind is forced into receiving the conclusions arrived at by its own laws of action.

For example, we go to the sea-shore, and observe the sands thrown up by the waves: note how the wash of the waves brings in layer upon layer, though with many irregularities; how the progressing waters raise ripples over the surface, which the next wave buries beneath other sands; how such sand-beds gradually increase in extent; how they are often continued out scores of miles beneath the sea, as the bottom of the shallow shore-waters; and that these submerged beds are formed through constant depositions from the ever moving waters. Then we go among the hard rocks, and find strata made of sand in irregular layers, much like those of the beach; and on opening some of the layers we discover ripple-marks covering the surface, as distinct and regular as if just made by the waves; or, in another place, we find the strata made up of regular layers of sand and clay alternating, such as form from the gradual settling of the muddy material emptied into the ocean by rivers, — or, in another place, layers of rounded, water-worn pebbles, such as occur beneath rapidly-moving waters, whether of waves or rivers. We remark that these hard rocks differ from the loose sand, clay, or pebbly deposits simply in being consolidated into a rock. Then, in other places, we discover these sand-deposits in all states of consolidation, from the soft, movable sand, through a half-compacted condition, to the gritty sandstone; and, further, we discover, perhaps, the very means of this consolidation, and see it in its progress, making rock out of sand or clay. By such steps as these, the mind is borne along irresistibly to the conclusion that rocks were slowly made through common-place operations.

We may see, on another sea-shore, extensive beds of limestone forming from shells and corals, having as firm a texture as any marble; we may watch the process of accumulation from the growth of corals and the wear of the waves, and find the remains of corals and shells in the compact bed. If we then meet with a limestone over the continent containing remains of corals, or shells, no firmer, not different in composition, but every way like the coral reef-rock, or the shell-rock of other regions, the mind, if allowed to act at all, will infer that the ancient limestone was as much a slowly-formed rock, made of corals, or shells, as the limestone of coral seas.

In a volcanic district, we witness the melted rock poured out in wide-spread layers and cooling into compact rock. and learn, after a little observation, that just such layers piled upon one another make the great volcanic mountain, although it may be ten thousand feet in height. We remark, further, that the fractured crust in those regions has often let out the lava to spread the surface with rock, even to great distances from the opening.

Should we, after this, discover essentially the same kind of rock in widespread beds, and trace out the fractures filled with it, leading downward through the subjacent strata, as if to some seat of fires, and discover marks of fire in the baking of the underlying beds, we use our reason in the only legitimate way, when we conclude that *these* beds were thrown out melted, even though they may be far from any volcanic centre.

If we see skeletons buried in sand and clay that we do not doubt are real skeletons of familiar animals, and then in a bed of rock discover other skeletons, but of unfamiliar animals, yet with every bone a true bone in form, texture, and composition, and every joint and limb modelled according to the plan in known species, we pass, by an unavoidable step, to the belief that the last is a relic of an animal as well as the former, and that it lies in its burial-place, although that burial-place be now the solid rock.

These few examples elucidate the mode of reasoning upon which geological deductions are based.

In using the present in order to reveal the past, we assume that the forces in the world are essentially the same through all time; for these forces are based on the very nature of matter, and could not have changed. The ocean has always had its waves, and those waves have ever acted in the same manner. Running water on the land has ever had the same power of wear and transportation and mathematical value to its force. The laws of chemistry, heat, electricity, and mechanics have been the same through time. The plan of living structures has been fundamentally one, for the whole series belongs to one system, as much almost as the parts of an animal to the one body; and the relations of life to light and heat, and to the atmosphere, have ever been the same as now.

The laws of the existing world, if perfectly known, are consequently a key to the past history. But this perfect knowledge implies a complete comprehension of nature in all her departments, — the departments of chemistry, physics, mechanics, physical geography, and each of the natural sciences. Thus furnished, we may scan the rocks with reference to the past ages, and feel confident that the truth will declare itself to the truth-loving mind.

As this extensive range of learning is not within the grasp of a single person, special departments have been carried forward by different individuals, each in his own line of research; for Geology as it stands is the combined result of the labors of many workers. But the system is now so far perfected that the ordinary mind may readily understand the great principles of the science, and comprehend the unity of plan in the earth's genesis.

SUBDIVISIONS OF GEOLOGY.

(1.) Like a plant or animal, the earth has its *systematic external form and features*, which should be reviewed.

(2.) Next, there are the *constituents of the structure* to be considered: first, their *nature*; secondly, their *general arrangement.*

(3.) Next, the successive stages in the formation of the structure, and the concurrent steps in the progress of life, through past time.

(4.) Next, the general plan or laws of progress in the earth and its life.

(5.) Finally, there are the active forces and mechanical agencies which were the means of physical progress, — spreading out and consolidating strata, raising mountains, ejecting lavas, wearing out valleys, bearing the material of the heights to the plains and oceans, enlarging the oceans, destroying life, and performing an efficient part in evolving the earth's structure and features.

These topics lead to the following subdivisions of the science: —

I. Physiographic Geology, — a general survey of the earth's surface-features.

II. Lithological Geology, — a description of the rock-material of the globe, its elements, rocks, and arrangement.

III. Historical Geology, — an account of the rocks in the order of their formation, and the contemporaneous events in geological history, including both stratigraphical and paleontological geology; and closing with a review of the system or laws of progress in the globe and its kingdoms of life.

IV. Dynamical Geology, — an account of the agencies or forces that have produced geological changes, and of the laws and methods of their action.

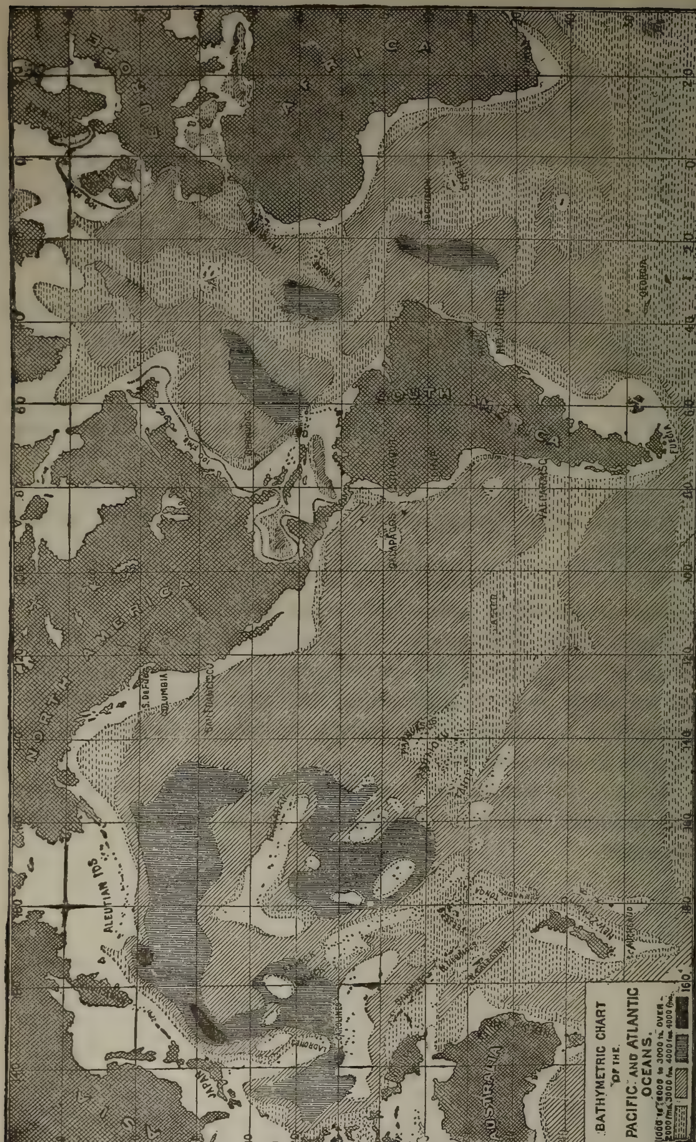

BATHYMETRIC CHART OF THE PACIFIC AND ATLANTIC OCEANS.
AFRICA
SOUTH AMERICA
NORTH AMERICA
ALEUTIAN IDS
AUSTRALIA

Fig. 2.

PART I.

PHYSIOGRAPHIC GEOLOGY.

THE systematic arrangement in the earth's features is every way as marked as that of any organic species; and this system over the exterior is an expression of the laws of structure beneath. The oceanic depressions or basins, with their ranges of islands, and the continental plains and elevations, all in orderly plan, are the ultimate results in the whole line of progress of the earth; and, by their very comprehensiveness as the earth's great feature-marks, they indicate the profoundest and most comprehensive movements in the forming sphere, just as the exterior configuration of an animal indicates its interior history. This subject is therefore an important one to the geologist, although its facts come also within the domain of physical geography. They lie at the top in geology as its last results, and, thus situated, constitute necessarily the arena of the physical geographer.

The following are the divisions in this department: —

1. The earth's general contour and surface-subdivisions.
2. System in the reliefs or surface-forms of the continental lands.
3. System in the courses of the earth's feature-lines.

These topics are followed by a brief review of, —

4. The system of oceanic movements and temperature.
5. The system of atmospheric movements and temperature.
6. The general law for the distribution of forest-regions, prairies, and deserts.

1. THE EARTH'S GENERAL CONTOUR AND SURFACE-SUBDIVISIONS.

The subjects under this head are — the earth's form; the distribution of land and water; the depth and true outlines of the oceanic depression; the subdivision of the land into continents; the height and kinds of surface of the continents.

(1.) **Spheroidal form.** — The earth has the form of a sphere with flattened poles, the distance from the centre to the pole being about

1-300th (accurately, $\frac{1}{302.4}$) shorter than from the centre to the equator. The earth's equatorial radius being 3,963 miles, the polar is about $13\frac{1}{4}$ miles less (exactly 13.2465 miles).

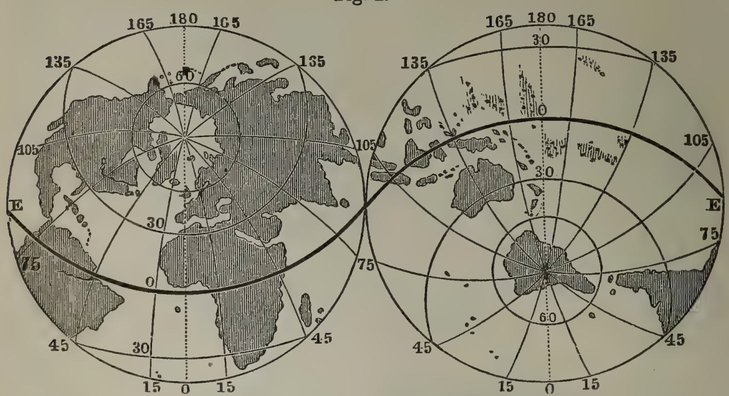
This is a fact of prime importance in geology, and an appropriate introduction to the science, inasmuch as it is the most obvious proof that the earth has a history, or has been in course of progress under secondary causes; for this flattening is in amount just that which the revolution at its actual rate would produce in a liquid globe having the size and density of the earth.

(2.) **General subdivisions of the surface.**—*Proportion of Land and Water.*—In the surface of the sphere there are about 8 parts of water to 3 of dry land, or, more exactly, 275 to $100 = 5^2 : 3^2$. The proportion of land north of the equator is nearly *three times* as great as that south. The zone containing the largest proportion of land is the north-temperate, the area equalling that of the water; while it is only one third that of the water in the torrid zone, and hardly one tenth (2-21ths) in the south-temperate.

Out of the 197,000,000 of square miles which make up the entire surface of the globe, 144,500,000 are water, and 52,500,000 land. In the northern hemisphere the land covers 38,900,000 square miles; in the southern, 13,600,000 square miles.

Land in one hemisphere.—If a globe be cut through the centre by a plane intersecting the meridian of 175° E. at the parallel of 40° N., one of the hemispheres thus made, the northern, will contain nearly

Fig. 1.



all the land of the globe, and the other be almost wholly water. The annexed map represents the two hemispheres.

The pole of the land-hemisphere in this map is in the western half of the British Channel; and, if this part, on a common globe, be placed in the zenith, under the brass meridian, the horizon-circle will then mark the line of division between the two hemispheres. The portions of land in the water-hemisphere are the extremity of South America below 25° S., and Australia, together with the islands of the

East Indies, the Pacific, and the Antarctic. London and Paris are situated very near the centre of the land-hemisphere.

General arrangement of the Oceans and Continents.[1] — Oceans and continents are the grander divisions of the earth's surface. But, while the continents are separate areas, the oceans occupy one continuous basin or channel. The waters surround the *Antarctic* and stretch *north* in three prolongations, — the Atlantic, the Pacific, and the Indian Oceans. The land is gathered about the *Arctic*, and reaches *south* in two great continental masses, the occidental and oriental; but the latter, through Africa and Australia, has two southern prolongations, making in all three, corresponding to the three oceans. Thus the continents and oceans interlock, the former narrowing southward, the latter northward.

The Atlantic is the narrow ocean, its average breadth being 2,800 miles. The Pacific is the broad ocean, being 6,000 miles across, or more than twice the breadth of the Atlantic. The occident, or America, is the narrow continent, about 2,200 miles in average breadth; the orient, the broad continent, 6,000 miles. Each continent has, therefore, as regards size, its representative ocean. This great difference of magnitude has an important bearing on the earth's geological history. The Pacific ocean, reckoning only to 62° S., has an area of 62,000,000 square miles, or nine and a half millions beyond the area of all the continents and islands.

(3.) **Oceanic depression.** — (*a.*) *Outline.* — The oceanic depression is a vast sunken area, varying in depth from 1,000 or less to, probably, 30,000 feet.

The true outline of the depression is not necessarily identical with the present line of coast. About the continents, there is often a region of shallow depths, which is only the submerged border of the continent. On the North American coast, off New Jersey, this submerged border extends out for 80 miles, with a depth, at this distance, of only 600 feet; and from this line the ocean-basin dips off at a steep angle. The true outline of the basin on this and other coasts is shown by

[1] In illustration of this part of the work, the reader is referred to the map at the close of the volume. It is a Mercator's chart of the world, which, while it exaggerates the polar regions, has the great advantage of giving correctly all courses, that is, the bearings of places and coasts. The trends of lines ("trend" means merely course or bearing) admit, therefore, of direct comparison upon such a chart. It is important in addition that the globe should be carefully studied in connection, in order to correct misapprehensions as to distances in the higher latitudes, and appreciate the convergences between lines that have the same compass-course.

The low lands of the continents on this chart, or those below 800 feet in elevation above the sea, are distinguished from the higher lands and plateaus by a lighter shading, and the axes of the mountain-ranges are indicated by black lines. The oceans are crossed by isothermal lines, which are explained beyond.

the dotted line on the chart. The slope for the 80 miles is only 1 foot in 700.

Great Britain is, on the same principle, a part of the European continent: the separating waters are under 600 feet in depth; and a large part of the German Ocean is only 93 feet. The true oceanic outline extends from Southern Norway around by the north of Scotland and southward into the Bay of Biscay. (See the dotted line on the chart.) In a similar manner, the East India Islands, down to a line running by the north of New Guinea and Celebes, are a part of Asia, the depth of the seas intermediate seldom exceeding 300 feet; while, south of the line mentioned, the islands are but fragments of Australia, the water being no deeper than over the submerged Asiatic plateau.[1]

(*b.*) *Depth of the Ocean* (see plate, page 8). The mean depth of the oceanic depression is about 12,000 feet; of the North Atlantic and North Pacific, about 15,000 feet. According to recent soundings, a depth of 27,000 feet occurs in the Atlantic, northwest of St. Thomas, and of 27,450 in the Pacific east of Japan. The Atlantic has a broad zigzag plateau ranging from north to south along its middle, lying at a depth of 6,000 to 12,000 feet, and conforming in trend to the American coast-line. The depth between Great Britain and Iceland is mostly under 600 feet and nowhere over 6,000 feet; along one line it is not over 3,000 feet. Between Ireland and Newfoundland the depth is 6,000 to 15,000. The Gulf of Mexico, which is about 1,000 miles broad, has a mean depth of 5,148 feet, and a maximum, according to recorded observations, of 12,714 feet (J. E. Hilgard).

(*c.*) *Character of the Oceanic Basins.* — To appreciate the oceanic basins, we must conceive of the earth without its water, — the depressed areas, thousands of miles across, sunk ten to perhaps fifty thousand feet below the bordering continental regions, and covering five eighths of the whole surface. The continents, in such a condition, would stand as elevated plateaus encircled by one great uneven basin. If the earth had been left thus, with but shallow lakes about the bottom, there would have been an ascent of five miles or more from the Atlantic basin to the lower part of the continental plateau, and one to five miles beyond this to scale the summits of the loftier mountains of the globe. The continents would have been wholly in the regions of the upper cold, all alpine and barren. This uneven surface of the Atlantic and Pacific has been levelled off to a plain by the waters of the ocean, the greatest heights of the world diminished more than one half, and the intolerable climates of such extremes of surface reduced to a genial condition, rendering nearly the whole land habitable, and giving moisture for clouds, rivers, and plants ; and, by the same means, distant points have been bound together, by a common highway, into one arena of history.

[1] Earl, *Jour. Indian Arch.*, II. ii. 278, and Wallace, *Malay Archipelago.*

(4.) **General view of the land.** — (*a.*) *Position of the land.* — The land of the globe has been stated to lie with its mass to the north, about the pole, and to narrow as it extends southward into the waters of the Southern hemisphere. The mean southern limit of the continental lands is the parallel of 45°, or just half-way from the equator to the south pole.

South America reaches only to 56° S. (Cape Horn being in 55° 58′), which is the latitude of Edinburgh or northern Labrador; Africa to 34° 51′ (Cape of Good Hope), nearly the latitude of the southern boundary of Tennessee, and 60 miles nearer the equator than Gibraltar; Tasmania (Van Diemen's Land) to 43½° S., nearly the latitude of Boston and northern Portugal.

(*b.*) *Distribution.* — The independent continental areas are three in number: America, one; Europe, Asia, and Africa, a second; Australia, the third. Through the East India Islands, Australia is approximately connected with Asia, nearly as South America with North America through the West Indies; and, regarding it as thus united, the great masses of land will be but two, — the American, or *Occidental*, and Europe, Asia, Africa, and Australia, or the *Oriental.*

These great masses of land are divided across from east to west by seas or archipelagoes. The West Indies, Mediterranean, Red Sea, and East Indies, with the connecting oceans, make a nearly complete band of water around the globe, as Professor Guyot observes, subdividing the Occident and Orient into north and south divisions. Cutting across 37 miles at the Isthmus of Darien, where at the lowest pass the greatest height above mean tide-level does not exceed 660 feet, as has been done at the Isthmus of Suez, where the summit-level is only 40 feet above the sea, the girth of water would be unbroken.

America is thus divided into North and South America. The oriental lands have one great area on the north, comprising Europe and Asia combined, and on the south (1) Africa, separated from Europe by the Mediterranean, and (2) Australia, separated from Asia by the East India seas. Thus the narrow Occident has one southern prolongation, and the wide Orient two. It is to be noted that the East and West Indies are very similar in form and position (see chart); and also that South America is situated with reference to North America very nearly as Australia is to Asia.

The Orient is thus equivalent to two Occidents in which the northern areas coalesce, — Europe and Africa one, Asia and Australia the other; so that there are really three doublets in the system of continental lands. Moreover, Europe and Asia have a semi-marine region between them; for the Caspian and Aral are salt seas, and they lie in a depression of the continent of great extent, — the Aral being near the level of the ocean, and the Caspian 80 to 100 feet below it.

The islands adjoining the continents are properly portions of the continental regions. Besides the examples mentioned on page 12, Japan and the ranges of islands of eastern Asia are strictly a part of Asia, for they conform in direction to the Asiatic system of heights, and are united to the main by shallow waters. Vancouver's Island and others north are similarly a part of North America; Chiloe, and the islands south to Cape Horn, a part of South America; and so in other cases.

The body of the continent of Africa lies in those latitudes which are almost wholly water in the American section, its western expansion corresponding to the indentation of the Caribbean Sea and the Gulf of Mexico.

(*c.*) *Oceanic Islands.* — The islands of mid-ocean are in lines, and are properly the summits of submerged mountain-chains. The Atlantic and Indian Oceans are mostly free from them. The Pacific contains about 675, which have, however, an aggregate area of only 80,000 square miles. Excluding New Caledonia and some other large islands in its southeastern part, the remaining 600 islands have an area of but 40,000 square miles, or less than that of New York State. The islands stretch off in a train from the Asiatic coast through the tropics in an east-southeast direction, and, soon crossing the equator, lie mostly in the southern tropic. The train extends to Easter Island and Sala-y-Gomez, in longitudes 110° and 105° W., a distance of 8,000 miles. The greatest depth of the ocean should be looked for outside of the limits of this train.

(*d.*) *Mean elevation.* — The mean height of the continents above the sea, exclusive of Australia and Africa, according to an estimate by Humboldt, is about 1,000 feet; and this is probably not far from the truth for all the land of the globe. As the area of the ocean and land is as 8 to 3, if all this land above the present water-level were transferred into the oceans, it would fill them 3-8ths of 1,000 or 375 feet; and, taking the average depth at 15,000 feet, it would take 40 times this amount to fill the oceanic depressions.

The mean height of the several continents has been stated as follows: Europe, 974 feet; Asia, 1,150; North America, 748; South America, 1,132; all America, 930; Europe and Asia, 1,010; Africa, probably about 1,600 feet; and Australia, perhaps 500. It has been estimated that the material of the Pyrenees spread over Europe would raise the surface only 6 feet; and the Alps, though four times larger in area, only 22 feet.

The extremes of level in the land, so far as now known, are, 1,300 feet *below* the level of the ocean, at the Dead Sea, and 29,000 feet *above* it, in Mount Everest of the Himalayas. Both of these points

occur on the continent of Asia, which has also its great depressed Caspian area. In America, below the ocean's level, Death's Valley, east of the Sierra Nevada, California, about latitude 36°, is 100 to 200 feet below the ocean's level.

(5.) **Subdivisions of the surface, and character of its reliefs.** — The surfaces of continents are conveniently divided into (1) low lands; (2) plateaus, or elevated table lands; (3) mountains. The limits between these subdivisions are quite indefinite, and are to be determined from a general survey of a country rather than from any specific definitions.

The *low lands* include the extended plains or country lying not far above tide-level. In general they are less than 1,000 feet above the sea; but they are marked off rather by their contrast with higher lands of the mountain-regions than by any precise altitude. The Mississippi Valley of the great interior region of the North American continent is an example; also the plains of the Amazon; the pampas of La Plata; the lower lands of Europe and Asia. The surface is usually undulating, and often hilly. Frequently the surface rises so gradually into the bordering mountain-declivities that the limit is altogether an arbitrary line, as in the case of the Mississippi plains and the Rocky Mountain slope.

A *mountain* is either an isolated peak, as Mount Etna, Mount Washington, Mount Blanc; or a ridge; or a series of ridges, sometimes grouped in many more or less parallel lines.

A *mountain-range* is made up of a series of ridges or elevations, closely related in position and direction, as the Green Mountain range, or, simply, the Green Mountains; the Sierra Nevada, the Ozark Mountains, etc. A *sierra* is, in Spanish, the name of a ridge or group of ridges of serrated or irregular outline.

A *mountain-chain* consists of two or more mountain ranges, which belong to a common region of elevation, and are generally either parallel or in consecutive lines, or consecutive curves, with often inferior transverse lines of heights. Thus, the Blue Ridge or range, the Alleghanies, and the Green Mountains, are parts of the Appalachian *Chain*, — a chain of heights that reaches from Canada to Alabama. So the Rocky Mountain chain includes many different ranges over a common region of elevation, the ranges composing it having been made at several different epochs.

A *cordillera* includes all the mountain-chains in the whole great belt of high land that borders a continent. Thus the Western Cordillera of North America comprises the Rocky Mountain chain, the Washington chain (Sierra Nevada and Cascade ranges), the Coast ranges, and other ranges of heights on the Pacific side of the continent. The

Eastern Cordillera of North America includes the Appalachian chain, the Adirondacks, and the Nova Scotia range. The term is thus used by J. D. Whitney.

The ridges of a common chain, and even those of a range, are not generally of the same age, as regards origin. Even the Green Mountains contain ridges that existed long before the main range had been elevated. The Appalachian chain has, in the Highlands of New Jersey, and the Blue Ridge, ridges of pre-Silurian age; in the Green Mountains, others which are mostly of middle-Silurian age; in the Alleghanies, others that are post-Carboniferous. Ridges, in topography, are grouped according to their relations in position and some related method of origin, but not according to time of origin.

A *plateau* is an extensive elevated region of flat or hilly surface, such as often occurs in mountainous regions. Any extensive range of country that is over a thousand feet in altitude would be called a plateau. It may lie along the course of a mountain-chain, or occupy a wide region between distant chains. The "Great Basin" between the Salt Lake and the Sierra Nevada is a plateau of the Rocky Mountain chain, 4,000 to 5,000 feet in elevation: the Salt Lake lies in its northeast corner, 4,200 feet above the sea. The plateau or table-land of Thibet lies between the Himalayas and the Kuen Lun Mountains next to the north, and is 11,500 to 13,000 feet in altitude; and the plateau of Mongolia (Desert of Gobi) occupies a vast region farther north, having a mean elevation of 4,000 feet. The State of New York is an elevated plateau, 1,500 to 1,700 feet in altitude north of the Mohawk Valley (an east-and-west valley), and 2,000 to 2,500 feet south of it; it lies in the course of the Appalachian Mountains.

Plateaus often have their mountain-ridges, like low lands.

MOUNTAINS. — The *form* of an *isolated mountain*-peak depends on its general slopes; that of a *ridge*, on (1) its slopes, (2) the outline of the crest, and (3) the course or arrangement of the consecutive parts of the ridge; that of a *chain*, on all these points, and in addition (4) the order or arrangement of the ridges in the chain.

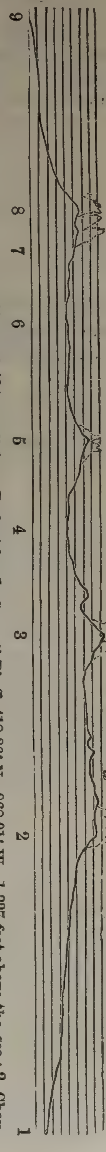
(*a.*) *Slopes of mountains.* — *The mountain-mass.* — The slopes of the larger mountains and mountain-chains are generally very gradual. Some of the largest volcanoes of the globe, as Etna and Loa (Hawaii), have a slope of only 6 to 8 degrees: the mountains are low cones, having a base of 50 miles or more.

The Rocky Mountains, Andes, and Appalachians are three examples of mountain-chains. The average eastern slope of the Rocky Mountains seldom exceeds 10 feet in a mile, which is about 1 foot in 500, equal to an angle of only 7 minutes. On the west the average slope is but little less gradual. The rise on the east continues for 600

miles, and the fall on the other side for 400 to 500 miles; the passes at the summit have a height of 4,944 to 10,000 feet; and above them, as well as over different parts of the slopes (especially on the west), there are ridges carrying the altitude above 14,000 feet. The highest part of the range is in Colorado, where the passes are 11,000 to 13,000 feet high; while in latitude 32° the passes are about 5,200 feet. The mountain-mass, therefore, is not a narrow barrier between the east and west, as might be inferred from the ordinary maps, but a vast yet gentle swell of the surface, having a base 1,000 miles in breadth, and the slopes diversified with various mountain-ridges, or spreading out in plateaus at different levels.

The annexed section (Fig. 2) of the Rocky Mountains along the parallels 41° and 42°, from Council Bluff, on the east, to Benicia, in California, illustrates this feature, although an exaggerated representation of the slopes, — the height being *seventy times* too great for the length.

Fig. 2.



Section of Rocky Mountains along the 41st and 42d parallel. — *Beckwith.* 1, Council Bluff, 41° 36′ N., 96° 01′ W., 1,327 feet above the sea; 2, Cheyenne Pass, 41° 12′ N., 105° 26′ W., 7,800 feet; *a*, Laramie Plains, 7,500 feet; *b*, Green River Basin, Fort Bridger, 6,780 feet; 3, Divide between Black and Muddy Creek, 8,373 feet, with Wahsatch Mountains; pass of Union Pacific R. R. at Aspen, 7,835 feet; 4, Salt Lake Basin, 4,238 feet; 5, Humboldt mountain-pass; 6, Great Basin, 600 miles broad, 4,100 to 4,500 feet; 7, 8, Sierra Nevada (7, Madelin Pass, 5,667 feet; 8, 5,736 feet, pass of Union Pacific R. R. at Creston, 7,030 feet); 9, Benicia, on the Pacific.

In the Andes the eastern slope is about 60 feet in a mile, and the western 100 to 150 feet; the passes are at heights from 12,500 to 16,160 feet, and the highest peak — Sorata in Bolivia — 25,290 feet. The slope is much more rapid than in the Rocky Mountains. But there is the same kind of mountain-mass variously diversified with ridges and plateaus. The existence of the great mountain-mass and its plateaus is directly connected with the existence of the main ridges. But it will be shown in another place that the ridges may have existed long before the mass had its present elevation above the sea.

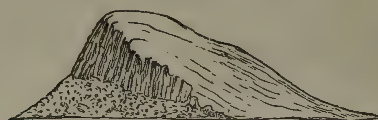
In the Appalachians — which include all the mountains from Georgia to the Gulf of St. Lawrence — the mountain-mass is very much smaller, and the component ridges are relatively more distinct and numerous; and still the general features are on the same principle. The greatest heights — those of North Carolina — are between 6,000 and 6,707 feet, and the average height is about 3,000 feet.

The Rocky Mountains, Andes, and Appalachians represent the three

types of chains: (1) the broad and lofty plateau type; (2) the narrow and lofty ridgy type, of which the Himalayas are another example; (3) the broad and many-folded type, of which the Juras are another example.

Illustrations. — It is common to err in estimating the angle of a slope. To the eyes of most travellers, a slope of 60° appears to be as steep as 80°, and one of 30° to be at least 50°. In a front view of a declivity it is not possible to judge rightly. A profile view should always be obtained and carefully observed before registering an opinion.

Fig. 3.



In fig. 3 the bluff front facing the left would be ordinarily called a vertical precipice, while its angle of slope is actually about 65°; and the talus of broken stones at its base would seem at first sight to be 60°, when really 40°.

Fig. 4.

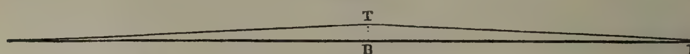


Fig. 5.

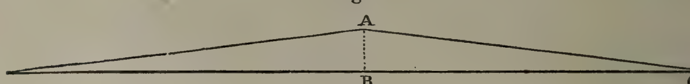


Fig. 6.

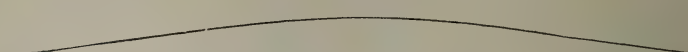
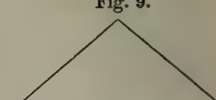


Fig. 4 represents a section of a volcanic mountain 3° in angle; 5, another, of 7°, — the average slope and form of Mount Kea, Hawaii; 6, the same slope with the top

Fig. 7.

Fig. 8.

Fig. 9.

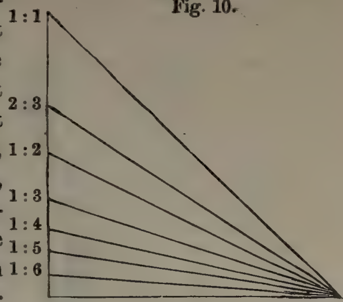


rounded, as in Mount Loa; 7, a slope of 15°; 8, Jorullo, in Mexico, which has one side 27° and the other 34°, as measured by N. S. Manross; 9, a slope of 40°, — the steepest of volcanic cones. The lofty volcanoes of the Andes are not steeper than in number 8, although frequently so pictured.

With a clinometer (see Fig. 102) held between the eye and the mountain, the angle of slope may be approximately measured. When no instrument is at hand, it is easy to estimate with the eye the number of times a vertical, as A B in Fig. 5, is contained in the semi-base, B C; and, this being ascertained, the angle of slope may be easily calculated. The ratio 1 : 1 corresponds to the angle 45°; 1 : 2 to 26° 34′; 1 : 3 to 18° 26′; 1 : 4 to 14° 2′; 1 : 5 to 11° $18\frac{1}{2}'$; 1 : 6 to 9° 28′; 1 : 7 to 8° 8′; 1 : 8 to 7° $7\frac{1}{2}'$; 1 : 9 to 6° $20\frac{1}{2}'$; 1 : 10 to 5° $42\frac{1}{2}'$; 1: 12 to 4° 46′; 1: 15 to 3° 49′; 1: 20 to 2° 52′. The inclinations corresponding to several of these ratios are represented in the following cut. (Fig. 10.)

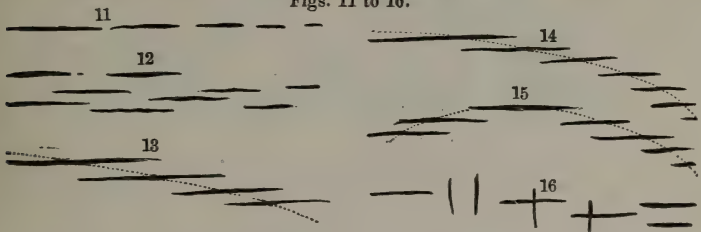
(*b.*) *Composition of mountain-chains.* — (1.) Mountain-chains have been stated to include several mountain-ridges; and even the ridges often consist of subordinate parts similar in arrangement. In the great chain of western North America, — the Rocky Mountains, — about the summit there are, in general, two prominent ranges; then, west of the summit, within 100 to 150 miles of the coast, there is the Washington Range, including the Cascade of Oregon and the Sierra Nevada of California, each with peaks over 14,000 feet in height; between this range and the summit there are in many parts several ridges more or less important; and between it and the coast other ridges make up what has been called the Coast Range. The Appalachians also, although but a small chain, consist of a series of nearly parallel ridges. In Virginia there are, beginning at the east, the Blue Ridge, the Shenandoah Ridge, and the Alleghany, besides others intermediate.

Fig. 10.



(2.) The ridges of a chain vary along its course. After continuing for a distance, they may gradually become lower and disappear; and while one is disappearing another may rise to the right or left; or the mountain may for scores of leagues be only a plateau without a high ridge, and then new ranges of elevations appear. The Rocky Mountains exemplify well this common characteristic, as is seen on any of the recent maps. The Sierra Nevada dies out where the Cascade Range begins; and each has minor examples of the same principle. The Andes are like the Rocky Mountains; only the parts are pressed into narrower compass, and the crest ranges are hence continuous for longer distances. The Appalachian ridges are rising and sinking along the course of the chain. The high land of the southwest terminates in New York; and just east stands the separate line

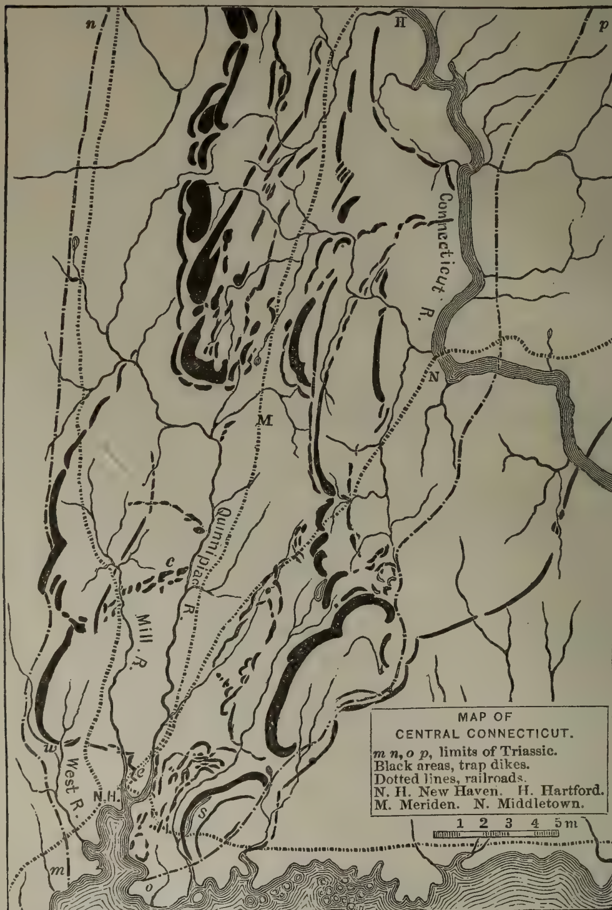
Figs. 11 to 16.



of the Green Mountains; and still farther eastward, — east of the Connecticut, — the range of the White Mountains.

The general idea of this composite structure is shown in Figs. 11 to

Fig. 17.



16, where each series of lines represents a series of ridges in a composite range. In Fig. 11 the series is simple and straight; in 12 it is still straight, but complex; in 13 the parallel parts are so arranged as still to make a nearly straight composite range; while in 14 and 15 the succession forms a curve; and in 16 there are transverse ridges in a complex series. In ridges or ranges thus compounded, the component parts may lie distinct, or they may so coalesce as not to be apparent.

These several conditions of interrupted and overlapping lines, constituting straight and curving chains, are illustrated among the islands of the oceans, the direction of coast-lines, and the courses of all the reliefs of the earth's surface, as is explained in the following pages. Figure 28 on page 34, representing the positions of the Australasian islands from New Hebrides to Sumatra, well exhibits the system of structure, — also Fig. 27, giving the courses and relative positions of the central groups of the Pacific, and Fig. 29, representing the Azores in the Atlantic; for the courses of islands are the courses of mountain chains. The South Atlantic and North Atlantic are two overlapping lines parallel in course, and on a still grander scale, one of them being much in advance or to the westward of the other, and each several thousand miles long.

The preceding map of the trap-ridges of Connecticut, from Percival's Report, presents well the structure. The narrow bands running nearly north and south represent the trap-ridges; they are in many nearly parallel lines; each consists of subordinate parts; and in several the parts lie in advancing or receding series. The extent of the series is small compared with a mountain-chain; and the ridges, few of which exceed 900 feet in height, are ejections through fissures beneath. But the parallelism in structure is perfect. The curves in some of the subordinate ridges have arisen from the fact that the fissures come up through a tilted sandstone, and the ejected rock escaped partly direct from the fissure and partly between the lifted strata of sandstone, and hence in a direction different from that of the fissure, the two directions together making the curve.

Solid dimensions of mountains. — The modes of calculating the mass of a mountain are the same that are given in treatises on mensuration. By a careful system of averaging, based on determinations of the slopes and altitudes, as far as practicable, the mountain-mass is reduced to one or more cones, pyramids, or prisms; and then the solid contents of the cones or pyramids are obtained by multiplying the area of the base into one third the altitude; or, for a triangular prism lying on one of its sides, the area of that side into half the length of a line drawn vertical to it from the opposite edge.

ELEVATED PLATEAUS, or *table-lands.* — Some examples of these plateaus have been mentioned (p. 16). The Llano Estacado (Staked Plain) in New Mexico and Upper Texas, southeast of Santa Fé, is another, of great extent, averaging 4,000 feet in elevation. The great Mexican plateau, in which the city of Mexico lies, has about that city a height of 7,482 feet, and slopes from this to 5,000 on the east and 4,000 on the west; and it stretches on north beyond the Mexican territory, blending with the plateaus of New Mexico. Above it rise many lofty volcanic cones, among which Popocatepetl is 17,799 feet high, Orizaba 17,373 feet, and Ixtaccihuatl 17,083. South Park in Colorado is in its northern part 9,500 to 10,000, and in its southern about a thousand less; and the average height of Middle Park is 8,500 feet.

The plateau of Quito, in the Andes, has a height of 10,000 feet; Quito itself 9,540 feet; and around it are Cotopaxi, 18,775 feet, Chimborazo, 21,421, Pichincha, 15,924, Cayambe, 19,535. The plateau of Bolivia is at an elevation of 12,900 feet, with Lake Titicaca, 12,830 feet, and the city of Potosi at 13,330 feet; and near are the volcanic peaks Illimani, 23,868 feet, Sorata, 25,290, Huayna Potosi, 20,260. In Europe, Spain is for the most part a plateau about 2,250 feet in average elevation; Auvergne, in

France, another, at about 1,100 feet; Bavaria another, at 1,660 feet. Persia is a plateau varying in elevation between 3,800 and 4,500 feet, with high ridges in many parts. The Abyssinian plateau, in Africa, has an average elevation of more than 7,000 feet; the region of Sahara, about 1,500; that of the interior of Africa south of the equator, about 2,500 feet.

River-Systems. — Plateaus and mountains are the sources of rivers. They pour the waters along many channels into the basin or low country toward which they slope; and the channels, as they continue on, unite into larger channels, and finally into one or more trunks which bear the waters to the sea. The basin and its surrounding slopes make up a river-system. The extent of such a region will vary with the position of the mountains and ocean. It may cover but a few hundred square miles, like the river-regions on a mountainous coast, or it may stretch over the larger part of a continent.

The interior of the United States belongs to one river-system, — that of the Mississippi; its tributary streams rise on the west among the snows of the Rocky Mountains, on the north in the central plateau of the continent, west of Lake Superior, near lat. 47° and beyond, long. 93°–96°, 1,680 feet in elevation, and on the east in the Appalachians, from western New York to Alabama. Besides the Mississippi, there are other rivers rising in the Rocky Mountains and flowing into the Gulf of Mexico; and, in a comprehensive view of the continent, these belong to the same great river-system.

The St. Lawrence represents another great river-system in North America, — a region which commences in the head-waters of Lake Superior, about the same central plateau of the continent that gives rise to the Mississippi, and embraces the great lakes with their tributaries and the rivers of Canada, — and flows finally northeastward into the Atlantic, following thus a northeast slope of the continent. North of Lake Superior and the head-waters of the Mississippi, as far as the parallel of 55°, there are other streams, which also flow northeastward, deriving some waters from the Rocky Mountains through the Saskatchewan, and reaching the ocean through Hudson's Bay. Winnipeg Lake is here included. These belong with the St. Lawrence, the whole together constituting a second continental river-system.

The Mackenzie is the central trunk of still another river-system, — the northern. Starting from near the parallel of 55°, it takes in the slopes of the Rocky Mountains adjoining, and much of the northern portion of the continent. Athabasca, Slave, and Bear Lakes lie in this district.

These are examples from among the river-systems of the world.

Lakes. — Lakes occupy depressions in the earth's surface which, from their depths or positions, are not completely drained by the existing streams, nor kept dry by the heat and drought of the climate

They occur (1) over the interior of table-lands, as about the head-waters of the Mississippi; (2) along the depressions between the great slopes of a continent, as the line of lakes in British North America running northwest from Lake Superior; (3) in confined areas among the ridges of mountains. The natural forms of continents — that is, their having high borders — tend to occasion the existence of lakes in their interior.

If a lake has no outlet to the ocean, its water is usually salt; and any plain or plateau whose streams dry up without communicating with the sea contains salt basins and efflorescences. The Caspian, Aral, and Dead Sea are some of the salt lakes of Asia; and the Great Salt Lake of the Rocky Mountains is a noted one on this continent. Many parts of the Rocky Mountains, the Great Basin of the West, the Pampas of South America, and all the desert regions of the globe, afford saline efflorescences.

The heights of some American lakes are as follows: Superior, 600 feet; Huron and Michigan, 574; Erie, 570; Ontario, 232; Winnipeg, 1,100; Lake of the Woods, 1,640; Great Salt Lake, 4,285; Yellowstone Lake, 7,788; Shoshone Lake, 7,870; Bear Lake, 5,931 feet.

2. SYSTEM IN THE RELIEFS OR SURFACE-FORMS OF THE CONTINENTS.

Law of the system. — The mountains, plateaus, low lands, and river-regions are the elements in the arrangement of which the system in the surface-form of the continents is exhibited. The law at the basis of the system depends on a relation between the continents and their bordering oceans, and is as follows: —

First. The continents have in general elevated mountain-borders and a low or basin-like interior.

Secondly. The highest border faces the larger ocean.

A survey of the continents in succession with reference to this law will exhibit both the unity of system among them and the peculiarities of each dependent on their different relations to the oceans.

(1.) **America.** — The two Americas are alike in lying between the Atlantic and the Pacific: moreover, South America is set so far to the east of North America (being east of the meridian of Niagara Falls), that each has an almost entire oceanic contour. Moreover, each is triangular in outline, with the widest part, or head, to the north.

North America, in accordance with the law, has on the Pacific side — the side of the great ocean — the Rocky Mountains, on the Atlantic side the low Appalachians, and between the two there is the great plain of the interior. This is seen in the annexed section (Fig. 18) from west to east: on the west, the Rocky Mountains, with the double

Fig. 18.

crest, at *b*; the Washington range at *a*; between *a b* the Great Basin; at *d* the Appalachians; *c* the Mississippi; and between *d* and *b* a section of the Mississippi river-system.

The Cascade and Nevada ranges are even more lofty in some of their summits than the crest-ridges of the Rocky chain. In the former there is a line of snowy cones from 10,000 to nearly 14,500 feet in elevation, including Mount Baker, near Puget's Sound, and, to the south of this, Mount St. Helen's, Mount Adams, and Mount Rainier, north of the Columbia, and, south, Mount Hood, Mount Pitt, Mount Jefferson, and the Shasta Peak, — the last 14,440 feet, according to Whitney. Still nearer the sea, there is what is called the Coast Range, consisting of lower elevations. Between the two lie the valley of the Sacramento and Joaquin, in California, and that of the Willamette, in Oregon.

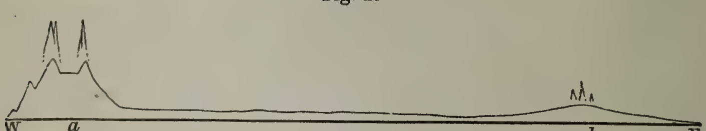
The Appalachians, on the east, reach an extreme height of but 6,700 feet, and are in general under 2,500 feet.

To the north of North America lies the small Arctic Ocean, much encumbered with land; and, correspondingly, there is no distinct mountain-chain facing the ocean. The mountains of Greenland are an independent system, pertaining to that semi-continent by itself.

The characteristics of the interior plain of the continent are well displayed in its river-systems: the great Mississippi system turned to the south, and making its exit into the Gulf of Mexico between the approaching extremities of the eastern and western mountain-ranges; the St. Lawrence sloping off northeastward; the Mackenzie, to the northward; the central area of the plain dividing the three systems being only about 1,700 feet above the ocean, — a less elevation than about the head-waters of the Ohio in the State of New York.

South America, like North America, has its great western range of mountains, and its smaller eastern (Fig. 19); and the Brazilian line (*b*)

Fig. 19.



is closely parallel to that of the Appalachians. As the Andes (*a*) face the South Pacific, a wider and probably much deeper ocean than the North Pacific, so they have more than twice the average height of the Rocky Mountains, and, moreover, they rise more abruptly from the ocean, with narrow shore-plains.

Unlike North America, South America has a broad ocean on the north, — the North Atlantic in its longest diameter; and, accordingly, this northern coast has its mountain-chain reaching along through Venezuela and Guiana.

The drainage of South America, as observed by Professor Guyot, is closely parallel with that of North America. There are, *first*, a southern system, — the La Plata, — reaching the Atlantic toward the south, between the converging east-and-west chains, like the Mississippi; *second*, an eastern system, — that of the Amazon, — corresponding to the St. Lawrence, reaching the same ocean just north of the eastern mountain-border; and, *third*, a northern system, — that of the Orinoco, — draining the slopes or mountains north of the Amazon system. The two Americas are thus singularly alike in system of structure: they are built on one model.

The relation of the oceans to the mountain-borders is so exact that the rule-of-three form of statement cannot be far from the truth. *As the size of the Appalachians to the size of the Atlantic, so is the size of the Rocky chain to the size of the Pacific.* Also, *As the height of the Rocky chain to the extent of the North Pacific, so are the height and boldness of the Andes to the extent of the South Pacific.*

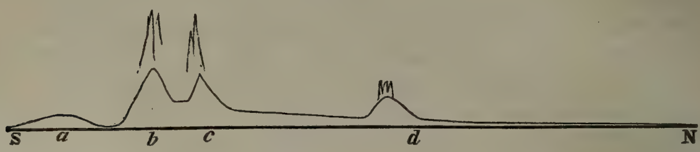
(2.) **Europe and Asia.** — The land covered by Europe and Asia is a single area or continent, only partially double in its nature (p. 13). Unlike either of the Americas, it lies east-and-west, with an extensive ocean facing Asia on the south; and its great feature-lines are in a large degree east-and-west. The Arctic Ocean is on the north; the North Atlantic is on the west; the North Pacific on the east; Africa and the Indian Ocean are on the south. The Atlantic is the smallest ocean; the North Pacific next, — for its average depth is probably not over 13,000 feet (p. 12), and it is much encumbered by islands to the west-of-south; the Indian Ocean next, — for it is full 5,000 miles wide in front of the Asiatic coast, and singularly free from islands. The boundary is a complex one, and the land between the Atlantic and Pacific over 6,000 miles broad.

On the side of the small North Atlantic, there are the mountains of Norway and the British Isles, the former having a mean height of 4,000 feet. On the Pacific side, there are loftier mountains, extending in several ranges from the far north to southern China, — the Stanovoi, Jablonoi, and Khingan ranges; and, off the coast, there is still another series of ranges, now partly submerged, — viz., those of Japan and other linear groups of islands. These stand in front of the interior chain, very much as the Cascade Range and Sierra Nevada of the Pacific border of America are in advance of the summit-ridges of the Rocky Mountains, and both are alike in being partly volcanic, with cones of great altitude.

Facing the still greater Indian Ocean, and looking southward, stand the Himalayas, — the loftiest of mountains, — called the Himalayas as far as Cashmere, and from there, where a new sweep in the curve begins, the Hindoo Koosh, — the whole over 2,000 miles in length : not so long, it is true, as the Andes, but continued as far as the ocean in front continues. The mean height of the Himalayas has been estimated at 16,000 feet; over forty of the peaks surpass Chimborazo. The Kuen Lun Mountains, to the north of the Himalayas, make another crest to the great chain, with Thibet between the two. Going westward, the mountains decline, though there are still ridges of great elevation.

On the north there are the wide Siberian plains, backed by the Altai, about half the Himalayas in height. The Altai thus have the

Fig. 20.



same relation to the Himalayas as the Appalachians to the Rocky Mountains, or the Brazilian Mountains to the Andes, yet with a striking difference in the immense shore-plain between them and the sea.

The sketch (Fig. 20) presents the general features to the eye. At *a*, there is the elevated land of India ; between *a* and *b*, the low river-plain at the base of the Himalayas ; at *b*, the Himalayas ; *b* to *c*, Plains of Thibet ; *c*, the Kuen Lun ridge ; *c* to *d*, Plains of Mongolia and Desert of Gobi ; at *d*, the Altai ; *d* to N, the Siberian plains.

The interior region of the continent, in its eastern half, is the plateau of Gobi and Mongolia, which, at 4,000 feet, is low compared with the mountains in front and rear. More to the westward, the region *c d* becomes intersected by the lofty Thian-shan Range. Still farther westward, the surface declines into the great depression occupied by the Caspian and Aral, part of which is below tide-level (p. 13).

The interior drainage-system for Asia is without outlet. The waters are shut up within the great basin, the Caspian and Aral being the seas which receive the part of those waters not lost in the plains. The Volga and other streams, from a region of a million of square miles, flow into the Caspian.

The Urals stand as a partial barrier between Asia and Europe, parallel nearly with the mountains of Norway.

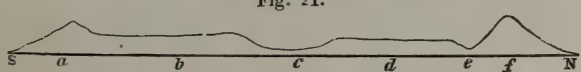
Europe has its separate system of elevations and interior plains ; but it is not necessary to dwell on it here.

The great continental mass accords with the law stated; — high borders proportioned in the case of each to the extent of the bordering oceans, and a general basin-like form.

(3.) **Africa.** — Africa has the Atlantic on the west, the larger Indian Ocean on the east, with Europe and the Mediterranean on the north, and the South Atlantic and Southern Ocean on the south. Its system of structure has been well explained by Professor Guyot. As he has stated, the northern half has the east-and-west position of Asia, and the southern the north-and-south of America; and its reliefs correspond with this structure. The Guinea coast belonging to the northern half projects west in front of the South Atlantic, and is faced by the east-and-west Kong Range; and opposite, on the Mediterranean, there are the Atlas Mountains, the High Plateau of which is about 3,000 feet, and one peak in the Atlas of Marocco is 13,000 feet high,— although the ridges are generally much lower (5,000 to 7,000 feet). The two thus oppose one another, like the Himalayas and Altai. The southern half of the continent has a border mountain-range the most of the way along the west and south. On the latter, which has a length of 700 miles, there are three or four parallel ridges, and some of the peaks are 4,000 to 7,000 feet high. Along the southwestern coast, the ranges are 4,000 to 5,000 feet, and on the Guinea coast the Kong Mountains 2,000 feet. Up the eastern coast, there is also a mountain-border, and higher than the western. By these border-ranges the interior of Africa is mostly shut off from the sea: it is a *shut-up* continent, as Guyot calls it. The loftiest mountains are in Abyssinia and Zanguebar, facing the Indian Ocean. Abyssinia is, to a great extent, an elevated plateau, 6,000 to 7,000 feet in height, with ridges reaching to 15,000 feet; and, farther south, in 3° 40′, stands the snowy Kilima-Njaro and Ngai, which are 19,000 feet high.

The interior of the *northern* or east-and-west half consists of (1) the Great Sahara region, a plateau of about 1,500 feet elevation, with its undulations and ridges, and some elevations of 6,000 feet; (2) an east-and-west depression on the north, between Sahara and the border-mountains, below the ocean's level in some parts, and being the region of the *oases*, all of which are 100 to 200 feet below tide level; (3) a partial east-and-west depression about the parallels 10° to 15° N., separating the Sahara plateau from the southern, and containing Lake Tchad, at an elevation of 800 feet. The interior of the *southern* half is a plateau 2,500 feet in average height.

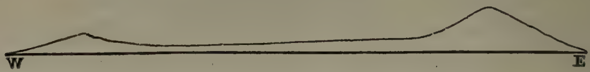
Fig. 21.



The sections Figs. 21 and 22 give a general idea of these features.

Fig. 21 is a section from south to north (the heights necessarily much exaggerated in proportion to the length); *a*, the southern mountains; *b*, the southern plateau; *c*, Lake Tchad depression; *d*, Sahara plateau; *e*, oases depression; *f*, mountains on the Mediterranean, of which there are two or three parallel ranges. Fig. 22 represents the surface outline from west to east through the southern half of the continent. In all these sections, all minor details are omitted, in order to bring out clearly the system, or continental model.

Fig. 22.



Africa has, therefore, a basin-like form, but is a double basin; and its highest mountains are on the side of the largest ocean, the Indian. The height of the mountains adjoining the Mediterranean is the only exception to the relation to the oceans; and this is small. Moreover, the position of the head of the continent against the continent of Europe with only the Mediterranean between, instead of an ocean, is a sufficient reason for the exception. Africa has some resemblance to America, but America turned about, with the most elevated border on the east instead of the west.

(4.) **Australia.** — Australia conforms also to the continental model. The highest mountains are on the side of the Pacific, — the larger of its border-oceans. The Australian Alps, in New South Wales, facing the southeast shores, have peaks 5,000 to 6,500 feet in height. The range is continued northward in the Blue Mountains, which are 3,000 to 4,000 feet high, with some more elevated summits, and, beyond these, in ridges under other names, the whole range being mostly between 2,000 and 6,000 feet in elevation. On the side of the Indian Ocean the heights are 1,500 to 2,000 feet. The interior is a low, arid region. The centre about 200 feet above the sea.

The continents thus exemplify the law laid down, and not merely as to high borders around a depressed interior, — a principle stated by many geographers, — but also as to the highest border being on the side of the greatest ocean.[1] The continents, then, are all built on one model, and, in their structures and origin, have a relation to the oceans that is of fundamental importance.

It is owing to this law that America and Europe literally stand facing one another, and pouring their waters and the treasures of the soil into a common channel, the Atlantic. America has her loftier mountains, not on the east, as a barrier to intercourse with Europe,

[1] First announced *American Jour. Sci.*, II., vols. iii. 398, iv. 92, 1847, and xxii. 335, 1856.

but off in the remote west, on the broad Pacific, where they stand open to the moist easterly winds as well as those of the west, to gather rains and snows, and make rivers and alluvial plains for the continent; and the waters of all the great streams, lakes, and seas make their way eastward to the narrow ocean that divides the civilized world. Europe has her slopes, rivers, and great seas opening into the same ocean; and even central Asia has her most natural outlet westward to the Atlantic. Thus, under this simple law, the civilized world is brought within one great country, the centre of which is the Atlantic, uniting the land by a convenient ferriage, and the sides the slopes of the Rocky Mountains and Andes on the *west* and the remote mountains of Mongolia, India, and Abyssinia on the *east*.[1]

This subject affords an answer to the inquiry, What is a continent as distinct from an island? It is a body of land so large as to have the typical basin-like form,— that is, mountain-borders about a low interior. The mountain-borders of the continents vary from 500 to 1,000 miles in breadth at base. Hence a continent cannot be less than a thousand miles (twice five hundred) in width.

3. SYSTEM IN THE COURSES OF THE EARTH'S FEATURE-LINES.

The system in the courses of the earth's outlines is exhibited alike over the oceans and continents, and all parts of the earth are thus drawn together into even a closer relation than appears in the principle already explained.

The principles established by the facts are as follows: That (1) two great systems of courses or trends prevail over the world, a *northwestern* and a *northeastern, transverse to one another;* (2) that the islands of the oceans, the outlines and reliefs of the continents, and the oceanic basins themselves, alike exemplify these systems; (3) that the mean or average directions of the two systems of trends are northwest-by-west and northeast-by-north; (4) that there are wide variations from these courses, but according to principle, and that these variations are often along curving lines; (5) that, whatever the variations, when the lines of the two systems meet, they meet nearly at right angles or transversely to one another.

(1.) **Islands of the Pacific Ocean.** — The lines or ranges of islands over the ocean are as regular and as long as the mountain-ranges of the land. To judge correctly of the seeming irregularities, it is necessary to consider that, in chains like the Rocky Mountains, or Andes, or Appalachians, the ridges vary their course many degrees as they continue on, sometimes sweeping around into some new direction, and

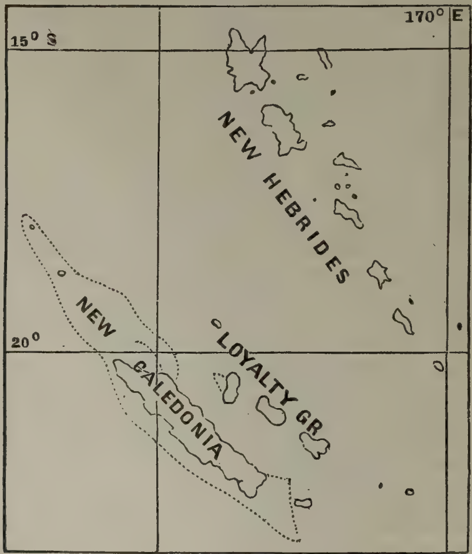
[1] See Guyot's *Earth and Man.*

then returning again more or less nearly to their former course, and that the peaks of a ridge are very far from being in an exact line even over a short course; again, that several approximately parallel courses make up a chain.

A. NORTHWESTERLY SYSTEM OF TRENDS.—In the southwestern Pacific, the *New Hebrides* (Fig. 23) show well this linear arrangement; and even each island is elongated in the same direction with the group. This direction is nearly northwest (N. 40° W.), and the length of the chain is 500 miles. *New Caledonia*, more to the southwest, has approximately the same course,—about northwest. Between New Hebrides and New Caledonia lies another parallel line, the *Loyalty Group*. The *Salomon Islands*, farther northwestward, are also a linear group. The chain is mostly a double one, consisting of two parallel ranges; and each island is linear, like the group, and with the same trend. The course is northwest-by-west, the length 600 miles.

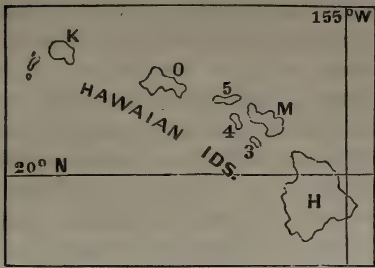
In the North Pacific, the Hawaian range has a west-northwest course. The Sandwich or Hawaian Islands (Fig. 24), from Hawaii to

Fig. 23.



Kauai, make up the southeasterly part of the range, about 400 miles in length. Beyond this, the line extends to 175° E., making a total length of nearly 2,000 miles,—a distance as great as from Boston to the Great Salt Lake in the Rocky Mountains, or from London to Alexandria. Moreover, in this chain, there are on Hawaii two sum-

Fig. 24.



H, Hawaii; M, Maui; 3, Kahoolawe; 4, Lanai; 5, Molokai; O, Oahu; K, Kauai.

mits nearly 14,000 feet in altitude; and, if the ocean around is 15,000 feet deep, the whole height of these peaks is just that of Mount Everest in the Himalayas.

Between these groups lie the islands of mid-ocean, all nearly parallel in their courses. Figs. 25, 26 are examples.

Fig. 25.

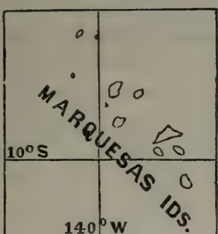
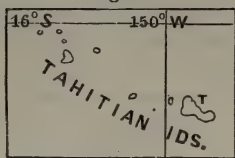


Fig. 26.



The following table gives the courses of the principal chains of the ocean:—

	Course.
Hawaian range	N. 64° W.
Marquesas Islands	N. 60° W.
Paumotu Archipelago	N. 60° W.
Tahitian or Society Islands	N. 62° W.
Hervey Islands	N. 65° W.
Samoan or Navigator Islands	N. 68° W.
Tarawan, Gilbert, or Kingsmill Islands	N. 34° W.
Ralick group	N. 37° W.
Radack group	N. 30° W.
New Hebrides	N. 40° W.
New Caledonia	N. 44° W.
North extremity of New Zealand	N. 50° W.
Salomon Islands	N. 57° W.
Louisiade group	N. 56° W.
New Ireland	N. 65° W.

B. Northeasterly system of trends. — The body of New Zealand has a northeast-by-north course. The line is continued to the south, through the Auckland and Macquarie Islands, to 58° S. To

the north, in the same line, near 30° S., lie the Kermadec Islands, and farther north, near 20° S., the Tonga or Friendly Islands.

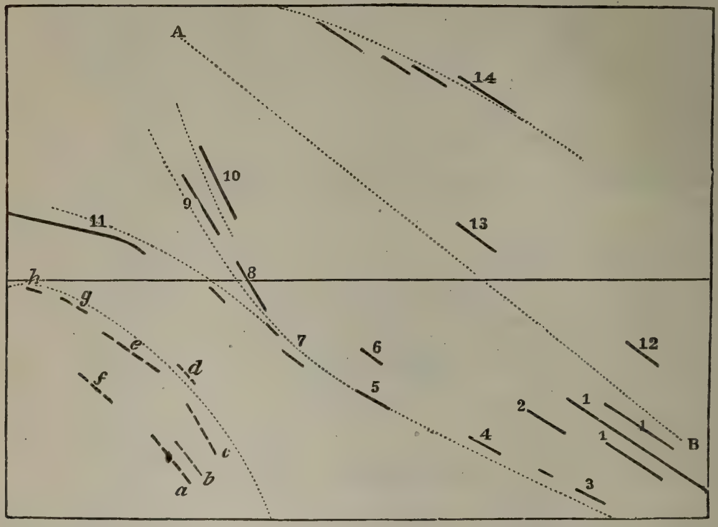
The Ladrones, north of the equator, follow the same general course. It also occurs in many groups of the northwesterly system characterizing subordinate parts of those groups. Thus, the westernmost of the Hawaian Islands, Nihau, lies in a north-northeast line, and the two lofty peaks of Hawaii have almost the same bearing.

Pacific island-chains. — The groups of Pacific islands, with a few exceptions, are not independent lines, but subordinate parts of island-chains. There are three great island-chains in the ocean which belong to the northwesterly system, — The *Hawaian*, the *Polynesian*, and the *Australasian*, — and, excluding the Ladrones, which pertain to the western Pacific, one belonging to the northeasterly system, viz.: the *Tongan* or *New Zealand chain.*

(1.) *Hawaian chain.* — This chain has already been described.

(2.) *Polynesian chain.* — This chain sweeps through the centre of the ocean, and has a length of 5,500 miles, or nearly one fourth the circumference of the globe. (See Fig. 27.) The Paumotu Archipelago (1), and the Tahitian, Rurutu, and Hervey Islands (2, 3, 4) are parallel lines in the chain, forming its eastern extremity; westward

Fig. 27.



1 to 10, the Polynesian chain: 1, Paumotu group; 2, Tahitian; 3, Rurutu group; 4, Hervey group; 5, Samoan, or Navigators'; 6, Vakaafo group; 7, Vaitupu group; 8, Gilbert's group; 9, Ralick; 10, Radack; 11, Carolines; 12, Marquesas; 13, Fanning group; 14, Hawaian. *a* to *h*, part of the Australasian chain: *a*, New Caledonia; *b*, Loyalty group; *c*, New Hebrides; *d*, Santa Cruz group; *e*, Salomon Islands; *f*, Louisiade group; *g*, New Ireland; *h*, Admiralty group.

there are the Samoan (5) and Tarawan (8) groups, and others intermediate; still northwestward there are the Radack and Ralick groups (9, 10), and in 20° N., on the same line, Wakes Island.

(*a.*) The chain, as is seen, consists of a series of parallel ranges, succeeding and overlapping along the general course, in the manner illustrated on page 19, when speaking of mountains. (*b.*) It varies its course gradually from west-northwest at the eastern extremity to north-northwest at the western. (*c.*) Its mean trend is northwest-by-west (N. 56° W.), the mean trend of all the groups of the northwesterly system in the ocean. (*d.*) The chain is a curving chain, convex to the southward, and marks the position of a great central elliptical basin of the Pacific having the same northwesterly trend. The Hawaian is on the opposite side of it, slightly convex to the north.

The Marquesan range (12, Fig. 27) lies in the same line with the Fanning group (13) to the northwest, just north of the equator; and, if a connection exists, another great chain is indicated, — a Marquesan chain.

(3.) *Australasian chain* (Fig. 28). — New Hebrides (K) and New Caledonia (M) belong to the Australasian island-chain. The line of New Hebrides is continued northwestward in the Salomon group and New Ireland (I), though bending a little more to the westward, and terminates in Admiralty land (G), near 145° E., where it becomes very nearly east-and-west: the length of the range is about 2,000 miles. Taking another range in the chain, New Caledonia (M), the course is continued in the Louisiade group (H); then the north side of New Guinea(E), which continues bending gradually till it becomes east-and-west, near 135° E. In the southeast, belonging to the same general line, there is the foot of the New Zealand boot (O). The coral islands between New Caledonia and Australia appear also to be other lines in the chain.

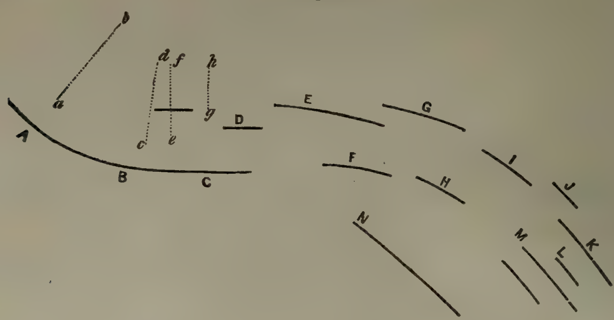
From New Guinea (E, F), the east-and-west course is taken up by Ceram (D), and again, more to the south, in the Java line of islands (A, B, C); and from Java (B) the chain again begins to rise northward, becoming northwest finally in Sumatra (A) and Malacca.

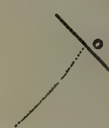
The several ranges make up one grand island-chain, with a double curvature, the whole nearly 6,000 miles long. In figure 28, a line stands for each group, and indicates its course. The composite nature of the chain is here apparent; as also the curving course, in connection with a prevailing conformity to a northwesterly trend.

(4.) *Blending of the Australasian and Polynesian island-chains.* — The two chains blend with one another in the region of the Carolines. (11, Fig. 27.) This large archipelago properly includes the Ralick and Radack groups (9, 10). At the Gilbert group (8) the Polynesian chain divides into two parts, — the Ralick and Radack ranges. But

the main body of the Archipelago (11, Fig. 27 and the chart) trends off to the westward, and is a third branch, conforming in direction to the Australasian system. (a to h, Fig. 27, are the same as M to G, Fig. 28.)

Fig. 28.





A, B, C, Sumatra and Java line of islands; D, Ceram; E, north coast of New Guinea; F, South New Guinea; G, Admiralty Islands; H, Louisiade group; I, Salomon; J, Santa Cruz group; K, New Hebrides; L, Loyalty group; M, New Caledonia; N, high lands of northeast Australia; O, New Zealand; *a b*, northwest shore of Borneo; *c d*, east Borneo; *e f*, west coast of Celebes; *g h*, west coast of Gilolo.

In other words, the Caroline Archipelago forks at its southeastern extremity, — one portion, the Gilbert, Radack, and Ralick Islands (8, 9, 10 in Fig. 27), conforming to the Polynesian system, while the great body of the Caroline Islands trend off more to the westward (No. 11), parallel with New Ireland and the Admiralty group (*g*, *h* of the same cut), and others of the Australasian system.

(5.) *New Zealand chain.* — The ranges in this chain are mentioned on p. 31. The whole length, from Macquarie Island, on the south, to Vavau, a volcanic island terminating the Tonga range, on the north, is 2,500 miles. To the east of New Zealand lie Chatham Island, Beverly, Campbell, and Emerald, which correspond to another range in the chain.

This transverse chain is at right angles with the Polynesian system at the point where the two meet. Moreover, it is nearly central to the ocean; and in its course farther north lie the Samoan and Hawaian Islands, two of the largest groups in the Polynesian system.

The central position, great length, and rectangularity to the northwest ranges give great significance to this New Zealand or northeasterly system of the ocean.

The large Feejee group lies near the intersection of the three Pacific chains; and hence its numerous islands do not conform to either one, though, the larger islands approximate most nearly to the last in direction.

(2.) **Pacific and Atlantic Oceans.** — The trend of the Pacific Ocean as a whole corresponds with that of its central chain of islands, and very nearly with the mean trend of the whole. It is a vast channel, elongated to the northwest. The range of heights along northeastern Australia (N, Fig. 28) runs northwesterly and passes by the head of the great gulf (Carpentaria) on the north; and the opposite side of the ocean along North America, or its bordering mountain-chain, has a similar mean trend. A straight line drawn from northern Japan through the eastern Paumotus to a point a little south of Cape Horn may be called the axis of the ocean. This axial line is nearly half the circumference of the globe in length, and the transverse diameter of the ocean full one-fourth the circumference: so that the facts relating to the Pacific chains must have a universal importance.

The *North Atlantic Ocean* trends to the northeast, — or at right angles, nearly, to the Pacific: this is the course of the coasts, and therefore of the channel. Taking the trend of the southeast coast of South America as the criterion, the *South Atlantic* conforms in direction to the North Atlantic.

The Asiatic coast of the Pacific has the direction of the northeasterly system. The course is not a nearly straight line, like the corresponding eastern coast of North America, but consists of a series of *curves*, which series is repeated in the island-chains off the coast and in the mountains of the country back. Moreover, the curves *meet* one another at right angles.

The last one, which is 1,800 miles long, commences in Formosa, and extends along by Luzon, Palawan, and western Borneo (*b a*, Fig. 28) to Sumatra, and terminates at *right angles* with Sumatra; and another furcation of it (*d c*) passes by eastern Borneo or Celebes, and terminates at *right angles* with Java and the islands just east. The rectangularity of the intersections is thus preserved; and the curve of the Australasian chain has in this way determined the triangular form of Borneo.

The Aleutian Islands (range No. 1) make a curve across from America to Kamchatka, in length 1,000 miles. The Kamchatka range (No. 2) commences at right angles with the termination of the Aleutian, and bends around till it strikes Japan at a right angle. The Japan range (No. 3) commences north in Saghalien, and curves around to Corea. The Loochoo range (No. 4) leaves Japan at a right angle, and curves around to Formosa. The Formosa range (No. 5) is explained above. There is apparently a repetition of the Formosa system in the Ladrones near longitude 145° E.

(3.) **East and West Indies.** — The general courses in the East Indies have been mentioned on pp. 33, 34. In the West Indies and Central America there is a repetition of the curves in the East Indies. The course of the range along Central America corresponds to Sumatra and Java; and the line of Florida and the islands to the south east makes another range in the same system.

The East and West Indies are very similar in their relations to the continents and oceans. About the *East* Indies Asia lies to the northwest and Australia to the southeast, just as North and South America lie about the *West* Indies; and the North Pacific and Indian Ocean have the same bearing about the former as the North Atlantic and South Pacific about the latter. The parallelism in the bends of the great chains is, hence, only a part in a wide system of geographical parallelisms.

(4.) **The American continents.** — In North America, the *northwest* system is seen in the general course of the Rocky Mountains, the Cascade Range and Sierra Nevada; in Florida; in the line of lakes, from Lake Superior to the mouth of the Mackenzie; in the southwest coast of Hudson's Bay; in the shores of Davis' Straits and Baffin's Bay; and with no greater divergences from a common course than occur in the Pacific. The *northeast* system is exemplified in the Atlantic coast from Newfoundland to Florida, and, still farther to the northeast, along the coast of Greenland; and to the southwest, along Yucatan, in Central America. The Appalachian Mountains, the river St. Lawrence to Lake Erie, and the northwest shore of Lake Superior, repeat this trend.

There are curves in the mountain-ranges of eastern North America, like those of eastern Asia. The Green Mountains run nearly north-and-south; but the continuation of this line of heights across New Jersey into Pennsylvania curves around gradually to the westward. The Alleghanies, in their course from Pennsylvania to Tennessee and Alabama, have the same curve. There appears also to be an outer curving range, bordering the ocean, extending from Newfoundland along Nova Scotia, then becoming submerged, though indicated in the sea-bottom, and continued by southeastern New England and Long Island.

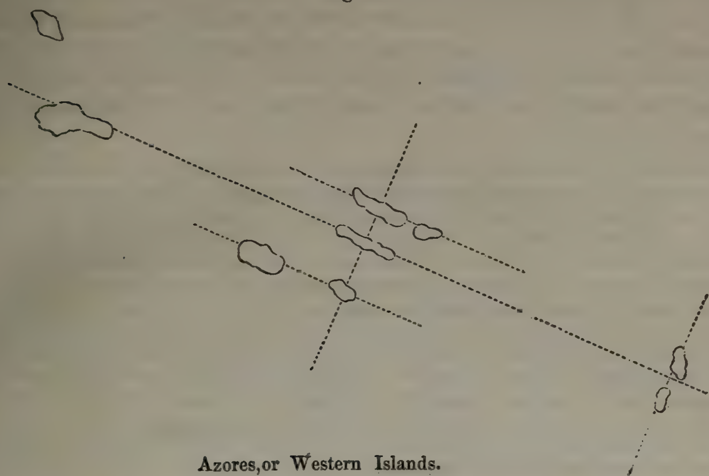
Between this latter range and that of the Green Mountains lies one of the great basins of ancient geological time, while to the westward of the Green Mountains and Alleghanies was the grand Interior basin of the continent. The two were to a great extent distinct in their geological history, being apparently independent in their coal-deposits and in some other formations.

In South America, the north coast has the same course as the Hawaian chain, or pertains to the northwest system; and the coast south of the east cape belongs to the northeast system. Hence the outline of the continent makes a right angle at the cape. The northwest system is repeated in the west coast by southern Peru and Bolivia, and the northeast in the coast of northern Peru to Darien: so that this northern part of South America, if the Bolivian line were continued

across, would have nearly the form of a parallelogram. South of Bolivia the Andes correspond to the northeast system, although more nearly north-and-south than usual.

(5.) **Islands of the Atlantic.** — The Azores have a west-northwest trend, like the Hawaian chain, and are partly in three lines, with evi-

Fig. 29.



Azores, or Western Islands.

dences also of the transverse system. The Canaries, as Von Buch has shown, present two courses at right angles with one another, — a northwest and a northeast.

Again, the line of the southeast coast of South America extends across the ocean, passing along the coast of Europe and the Baltic; and the mountains of Norway and the feature-lines of Great Britain are parallel to it.

(6.) **Asia and Europe.** — In Asia, the Sumatra line, taken up by Malacca, turns northward, until it joins the knot of mountains formed by the meeting of the range facing the Pacific and that facing the Indian Ocean. At this point, and partly in continuation of a Chinese range, commence the majestic Himalayas, — at first east-and-west, at right angles with the termination of the Malacca line, then gradually rising to west-northwest. The course is continued northwestward in the Hindoo Koosh, extending toward the Caspian, — in the Caucasus, beyond the Caspian, and in the Carpathians, beyond the Black Sea. The northwest course appears also in the Persian Gulf, and the plateaus adjoining, in the Red Sea, the Adriatic and the Apennines.

Recapitulation. — From this survey of the continents and oceans it follows: —

That, while there are many variations in the courses of the earth's feature-lines, there are two directions of prevalent trends, — the northwesterly and the northeasterly; that the Pacific and Atlantic have thereby their positions and forms, the islands of the oceans their systematic groupings, the continents their triangular and rectangular outlines, and the very physiognomy of the globe an accordance with some comprehensive law. The ocean's islands are no labyrinths; the surface of the sphere is no hap-hazard scattering of valleys and plains; but even the continents have a common type of structure, and every point and lineament on their surface and over the waters is an ordered part in the grand structure.

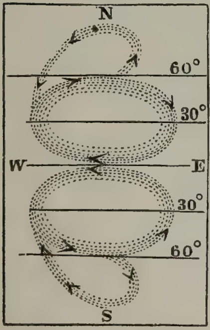
It has been pointed out, first by Professor R. Owen, of Indiana,[1] that the outlines of the continents lie in the direction of great circles of the sphere, which great circles are, in general, tangential to the arctic or antarctic circle. By placing the north pole of a globe at the elevation 23° 28′ (equal to the distance of the arctic circle from the pole or the tropical from the equator), then, on revolving the globe eastward or westward, part of these continental outlines, on coming down to the horizon of the globe, will be found to coincide with it; and, on elevating the south pole in the same manner, there will be other coincidences. Other great lines, as part of those of the Pacific, are tangents to the tropical circles instead of the arctic. But there are other equally important lines which accord with neither of these two systems, and a diversity of exceptions when we compare the lines over the surfaces of the continents and oceans.

Still, the coincidences as regards the continental outlines are so striking that they must be received as a fact, whether we are able or not to find an explanation, or bring them into harmony with other great lines.

4. SYSTEM IN THE OCEANIC MOVEMENTS AND TEMPERATURE.

(1.) **System of oceanic movements.** — The general courses of the ocean's currents are much modified by the forms and positions of the oceans; but the plan or system for each ocean, north or south of the equator, is the same. This system is illustrated in the annexed figure (Fig. 30), in which all minor movements are avoided in order to present only the predominant courses. W E is the equator in either ocean; 30°, 60°, the parallels so named; N, S, the opposite polar regions: the arrow-heads show the direction of the movement.

Fig. 30.



The main facts are as follow: —

(1.) A flow in either tropic (see figure) *from the east*, and in the higher temperate latitudes *from the west*, the one flow turning into the other, making an elliptical movement. The tropical waters may pass into the extratropical regions in all longitudes; but the movement is appreciable only toward the sides of the oceans.

(2.) A flow of a part of the easterly-flowing

[1] *Key to the Geology of the Globe*, 8vo, New York, 1857, and *Am. Jour. Sci.*, II. xxv. 130.

extratropical waters (see Fig. 30) outward toward the polar region, to return thence with the polar waters mainly along the western side of the ocean (though partly by the eastern).

(3.) A flow of the colder current under the warmer when the two meet, since cold water is heavier than warm.

(4.) A lifting of the deep-seated cold currents to the surface along the sides of a continent or island, or over a submerged bank, as on the west coast of South America.

(5.) A movement of the circuit, as a whole, some degrees to the north or south with the change of the seasons, or as the sun passes to the north or south of the equator.

(6.) On the west side of an ocean (see Fig. 30), the cold northerly current is mainly from the polar latitudes; on the east side, it is mainly from the high temperate latitudes, being the cooled extratropical flow on its return.

(7.) The tropical current has great depth, being a profound movement of the ocean, and it is bent northward in its onward course by the deep, submerged sides of the continents. The Gulf Stream has consequently its main limit 80 to 100 miles from the American coast, where the ocean commences its abrupt depths (p. 11). Hence, a submergence of a portion of a continent sufficient to give the body of the current a free discharge over it would have to be of great depth, — probably two thousand feet at least.

The usual explanation of the courses is as follows: As the earth rotates to the eastward, the westward tropical flow is due simply to a slight lagging of the waters in those latitudes. But transfer these waters toward the pole, where the earth's surface moves less rapidly (the rate of motion varies as the cosine of latitude), and then they may move faster than the earth's surface, and so have a movement to the *eastward.* The earth's rotation is not supposed to be a *cause of motion* in the waters; but, there being a movement, for other reasons (which it is not necessary here to consider), from the equator toward the poles, and from the higher latitudes toward the equator, *it gives easting* to the flow in the former direction, and *westing* to the flow in the latter.

On the same principle, any waters flowing from the polar regions (where the earth's motion at surface is slow) toward the equator would be thrown mainly against the *west side* of the oceans (as the Labrador current in the North Atlantic); for they have no power to keep up with the earth's motion. But the waters flowing toward the pole, that have not lost much of their previous eastward moving force, may descend to lower latitudes along the east side of the ocean.

Put the above figure in either the Atlantic or Pacific, and the system for the ocean will be apparent at a glance.

In the North Atlantic, the deep tropical current *from the east* is turned to the northward along the West India islands, and there becomes the Gulf Stream; it flows by Florida to the northeast, following nearly the outline of the oceanic basin; it passes the Newfoundland bank, and stretches over toward Europe; then a part bends southeastward to join the tropical current and complete the ellipse, the centre of which is the Sargasso Sea, abounding in seaweeds and calms. Another large portion continues on northeastward, over the region between Britain and Iceland, to the poles. From the polar region, it returns along by Eastern Greenland, Davis' Straits and other passages, pressing against the North American coast, throwing cold water into the Gulf of St. Lawrence, bringing icebergs to the Newfoundland banks, and continuing on southward to the West India islands and South American coast, where it produces slight effects in the temperature of the coast-waters. Cape Cod stands out so far that the influence of the cold current is less strongly felt on the shores south than north; and Cape Hatteras cuts off still another portion.

In the South Atlantic, there is the tropical flow from the east; the bending south toward Rio Janeiro; the turn across toward Cape of Good Hope; and the bending again, northward, of the waters now cold. But, owing to the manner in which the channels of the South Atlantic and North Atlantic are united, a large part of the tropical current of the former goes to swell the tropical current and Gulf Stream of the latter.

In the North Pacific, there is the same system, modified mainly by this, that the connection with the polar regions is only through the narrow and shallow Behring Straits. There is a current answering to the "Gulf Stream" off Japan, and another corresponding to the "Labrador current" along the whole length of the Asiatic coast, perceptible by the temperature if not by the movement.

In the South Pacific, there are traces of a "Gulf Stream" — that is, of an outward-bound tropical current — off Australia, noticed by Captain Wilkes. The inward extratropical current, chilled by its southern course, is a very important one to Western South America, as it carries cool waters quite to the equator.

In the Indian Ocean, the system exists, but with a modification depending on the fact that the ocean has no extended northern area. The outward tropical current is perceived off southeastern Africa.

The surface-currents of the ocean are more or less modified by changes in the winds. On this and on other related topics barely glanced at in this brief review, the reader may refer to treatises on Meteorology or Physical Geography.

(2.) **Oceanic temperature.** — The movement of the oceanic cur-

rents tends to distribute tropical heat toward the poles, and polar cold, in a less degree, toward the tropics; and hence the courses of the currents modify widely the distribution of oceanic heat. The chart at the close of this volume contains a series of oceanic isothermal lines drawn through places of equal cold for the coldest month of the year. The line of 68° F., for example, passes through points in which the mean temperature of the water in the coldest month of the year is 68° F.; so with the lines of 62°, 56°, etc.[1] All of the chart between the lines of 68°, north and south of the equator, is called the *Torrid Zone* of the ocean's waters; the region between 68° and 35°, the *Temperate Zone*, and that beyond 35°, the *Frigid Zone*. The line of 68° is that limiting the coral-reef seas of the globe, so that the coral-reef seas and Torrid Zone thus have the same limits.

The regions between the successive lines, as 80° and 80°, 80° and 74°, 74° and 68°, 68° and 62°, 62° and 56°, 56° and 50°, and so on, have special names on the chart. They are as follow: —

1. Torrid Zone. — Super-torrid, torrid, and sub-torrid regions.
2. Temperate Zone. — Warm-temperate, temperate, sub-temperate, cold-temperate, and sub-frigid regions.
3. Frigid Zone.

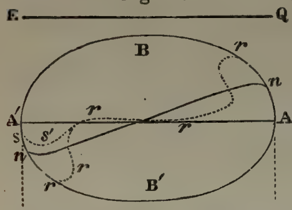
They are convenient with reference to the geographical distribution of oceanic species.

Since the tropical (the westward) currents are warm, and the extra-tropical (the eastward) necessarily cold, the elliptical interplay explained must carry the *warm* waters *away* from the equator on the *west* side of the oceans, and the *cold* waters *toward* the equator on the *east* side. The distribution of temperature thus indicates the currents. In each elliptical circuit, therefore, the line of 68° F. should be an oblique diagonal line to the ellipse; and thus it is in the North Atlantic, the South Atlantic, the North Pacific, the South Pacific (though less distinctly here, as the ocean is so broad), and the Indian Ocean. The torrid-temperature zones are very narrow to the eastward and broad to the westward. The temperate zones press toward the equator against western Africa and Europe, and western America. On the South American coast, this is so marked that a tropical temperature does not touch the whole coast, except near the equator, and does not even reach the Galapagos under the equator off the coast, as shown by the course of the isothermal line of 68°. So, in the South Atlantic, the colder waters extend north to within six degrees of the equator, where the line of 68° leaves the African coast. The continuation of the Gulf Stream up between Norway and Iceland is shown by the great loops in the lines of 44° and 35°. The effect of the Labrador or polar

[1] As the lines are lines of equal extreme cold, instead of heat, such a chart is named an *isocrymal* chart (from ἴσος, *equal*, and κρύμος, *extreme cold*).

current, in cooling the waters on the coast of America, is also well exhibited in the bending southward near the coast of all the lines from 68° to 35°. The polar current is even more strongly marked in the same way on the Asiatic coast. The lines from 74° to 35° have long flexures southward adjoining the coast, and the line of 68° comes down to within fifteen degrees of the equator. These waters pass southward mostly as a submarine current, and are felt in the East Indies, making a southward bend in the heat equator.

Fig. 31.



In figure 31, the elliptical line (A′B′ AB) represents the course of the current in an ocean south of the equator (E Q). If now the movement in the circuit were equable, an isothermal line, as that of 68°, would extend obliquely across, as *n n:* it would be thrown south on the west side of the ocean by the warmth of the torrid zone, and north on the east side by the cooling influence derived from its flow in the cold-temperate zone. But, if the current, instead of being equable throughout the area, were mainly apparent near the continents (as is actually the fact), the isothermal line should take a long bend near the coasts, as in the line A′ *r′ r r r r* A, or a shorter bend A′ *s s′*, according to the nature of the current. This form of the isothermal line of 68° on the chart, indicates the existence of the circuit movement in the ocean, and also some of its characteristics.[1]

The following are some of the uses of this subject to the geologist: —

1. A wide difference is noted between the water-temperatures of the opposite sides of an ocean. The regions named *temperate* and *subtemperate* occupy the most of the Mediterranean Sea, and the Spanish and part of the African coast, on the European side, and yet have no existence on the American, owing to the meeting at Cape Hatteras of the cold northern waters with the warm southern. Compare also other oceans and coasts on the map.

2. Consequently, the marine productions of coasts or seas in the same latitudes differ widely. Corals grow at the Bermudas in 34° N., where the warmth of the Gulf Stream reaches, and, at the same time, are excluded from the Galapagos under the equator. Other examples of the same principle are obvious on the chart.

3. The *west* side of an ocean (as in the northern hemisphere) feels most the cold northerly currents, when the continent extends into the polar latitudes; but the *east* side (as in the southern hemisphere), if the continent stops short of those latitudes. There is hence, in the present age, a striking difference between the northern and southern hemispheres.

4. Changes of level in the lands of the globe have caused changes of climates in the ancient world.

[1] See paper by the author, in *Amer. Jour. Sci.*, II. xxvi. 231.

5. Knowing the temperature limiting the coral-reefs of the present era, or any species of plants or animals, the geologist has a gauge for comparing the present distribution of temperature and life with the past.

5. ATMOSPHERIC CURRENTS AND TEMPERATURE.

General System. — The system of atmospheric movement has a general parallelism with that of the ocean. In the tropics, the flow is *from the east*, constituting what are called the *trades;* in high-temperate latitudes, it is *from the west;* and the two pass into one another in mutual interplay. Between these there is, in mid-ocean, a region of calms. The extratropical winds also in part pass on to the poles, to return, as northeast, north, and northwest winds, toward the equator.

The cause of the motion is not now considered, as it is here in place only to present in a comprehensive manner the earth's exterior features. The causes varying the directions consist in — (1) the temperature of the land and ocean; (2) the form of the land (mountains being barriers to a flow, retarding by friction, etc.); (3) difference of density of cold and warm air; (4) changing seasons, etc. But these sources of disturbance only modify without suspending the system of movement.

Climate. — Climate, while dependent largely on the latitude, is modified by the atmospheric and oceanic movements and the distribution of land and water. A few general facts are here mentioned, in order to complete this survey of the earth's physiography.

1. The land takes up heat rapidly in summer, and, in the north, becomes frozen and snow-clad in winter. Land-winds may, consequently, be intensely hot or intensely cold; and hence lands have a tendency to produce extremes of climate.

A place on the continents having a mean January temperature of 50° (a very warm temperature for that season) is to be found only in warm latitudes, and one with a mean July temperature of 50° (a cold temperature for the season) only in the colder zones of the globe. The mean January temperature of New York is 31½° F., while the mean July temperature is 73°. Now, in North America, the January isothermal line of 50° almost touches the Gulf of Mexico, and the July line of 50° passes near the mouth of Mackenzie River, or the Arctic circle, — the extreme winters and intense summers causing this great change. In Asia, again, the January line of 50° runs just north of Canton, near 26° N., and the July line of 50° touches the Arctic Ocean at the mouth of the Lena, in 72° N., making a difference of 46° of latitude, or nearly 3,000 miles, as the effect of the land on the climate.

2. The waters of the oceans remain unfrozen even far toward the pole, unless crowded with lands, their perpetual movements tending to produce a uniformity of temperature over the globe; and hence winds from the oceans or any large body of water are moderating, and never very cold. They produce what is called an *insular* climate.

Great Britain is tempered in its climate by its winds and the oceanic current (the Gulf Stream). Fuegia, which is almost surrounded by water, also has an insular climate, — the winter's cold falling little below 32°, although below 53° S. latitude.

3. Absence of land from high latitudes is equivalent to an absence of the source of extreme cold; and from tropical latitudes, that of extreme heat; and the sinking of all lands would diminish greatly both extremes. But sinking high-latitude lands also diminishes the extreme of heat, since the lands become very much heated in summer, and this heat is diffused by the winds. Fuegia, on this principle, has a sub alpine climate with alpine vegetation; and Britain might approximate to the same condition if the Gulf Stream could be diverted into another ocean.

The mean temperature of the Northern hemisphere is stated by Dove at 60° F., and of the Southern at 56° F., while the extremes for the globe, taking the annual means, are 80° F. and *zero.* If there were no land, the mean temperature would probably be but little above what it is now, or not far from 60° for the whole globe.

6. DISTRIBUTION OF FOREST-REGIONS, PRAIRIES, AND DESERTS.

The laws of the winds are the basis of the distribution of sterility and fertility.

1. The warm tropical winds, or trades, are moist winds; and, blowing against cooler land, or meeting cooler currents of air, they drop the moisture in rain or snow. Consequently, the side of the continents or of an island struck by them — that is, the eastern, — is the moister side.

2. The cool extratropical winds from the westward and high latitudes are only moderately moist (for the capacity for moisture depends on the temperature); blowing against a coast, and bending toward the equator, they become warmer, and continue to take more moisture as they heat up; and hence they are *drying* winds. Consequently, the side of a continent struck by these westerly currents — that is, the *western* — is the drier side.

There is, therefore, double reason for the difference in moisture between the opposite sides of a continent.

Consequently, the annual amount of rain falling in tropical South America is 116 inches, while on the opposite side of the Atlantic it is 76 inches. In the temperate zone of the United States east of the Mississippi, the average fall is about 44 inches; in Europe, only 32. America is hence, as styled by Professor Guyot, the Forest Continent; and, where the moisture is not quite sufficient for forests, she has her great prairies or pampas.

The particular latitudes of western coasts most affected by the drying westerly winds — those between 28° and 32° — are generally excessively arid, and sometimes true deserts.[1]

The desert of Atacama, between Chili and Peru, the semi-desert of California, the desert of Sahara, and the arid plains of Australia lie in these latitudes. The aridity on the North American coast is felt even beyond Oregon, through half the year. The snowy peak of Mount St. Helen's, 12,000 feet high, in latitude 43°, stands for weeks together without a cloud. The region of the Sacramento has rain ordinarily only during three or four months of the year.

As the first high lands struck by moist winds usually take away the moisture, these winds afterward have little or none for the lands beyond. Here is the second great source of desert-regions. For this reason, the region of the eastern Rocky Mountain slope, and the summits of these mountains, are dry and barren; and, on the same principle, an island like Hawaii has its wet side and its excessively dry side.

Under the influence of the two causes, the Sahara is continued in an arid country across from Africa, over Arabia and Persia, to Mongolia or the Desert of Gobi, in central Asia.

It is well for America that her great mountains stand in the far west, instead of on her eastern borders, to intercept the atmospheric moisture and pour it immediately back into the ocean. The waters of the great Gulf of Mexico (which has almost the area of the United States east of the Mississippi) and those of the Mediterranean are a provision against drought for the continents adjoining. It is bad for Africa that her loftiest mountains are on her eastern border.

It is thus seen that prairies, forest-regions, and deserts are located by the winds and temperature in connection with the general configuration of the land.

The movements of the atmosphere and ocean's waters, and the surface-arrangements of heat and cold, drought and moisture, sand-plains and verdure, have a comprehensive disposing cause in the simple *rotation of the earth.* Besides giving an east and west to the globe, and zones from the poles to the equator, this rotation has made an east and west to the atmospheric and oceanic movements, and thence to the continents, causing the eastern borders of the oceans and land to differ in various ways from the western, and producing corresponding peculiarities over their broad surface. The continents, though in nearly the same latitudes on the same sphere, have thence derived many of those diversities of climate and surface which, through all epochs to the present, have impressed on each an individual character, — an in-

[1] W. C. Redfield, in *Amer. Jour. Sci.*, xxv. 139, 1834, and xxxiii. 261, 1838.

dividuality apparent even in its plants and animals. The study of the existing Fauna and Flora of the earth brings out this distinctive character of each with great force; but the review of geological history makes it still more evident, by exhibiting the truth in a continued succession of faunas and floras, giving this individuality a history looking back to "the beginning."

The great truth is taught by the air and waters, as well as by the lands, that the diversity about us, which seems endless and without order, is an exhibition of perfect system under law. If the earth has its barren ice-fields about the poles, and its deserts, no less barren, toward the equator, they are not accidents in the making, but results involved in the scheme from its very foundation.

PART II.

LITHOLOGICAL GEOLOGY.

LITHOLOGICAL GEOLOGY treats of the materials in the earth's structure: *first*, their *constitution*; *secondly*, their *arrangement* or *condition*.

The earth's interior is open to direct investigation to a depth of only fifteen or sixteen miles; and hence the science is confined to a thin crust of the sphere, sixteen miles being but one five-hundredth of the earth's diameter.

I. CONSTITUTION OF ROCKS.

Rocks. — A rock is any bed, layer or mass of the material of the earth's crust. The term, in common language, is restricted to the consolidated material. But in Geology it is often applied to all kinds, whether solid or uncompacted earth, so as to include, besides granite, limestone, conglomerates, sandstone, clay-slates, and the like solid rocks, gravel-beds, clay-beds, alluvium, and any loose deposits, whenever arranged in regular layers or strata as a result of natural causes.

The constituents of rocks are minerals. But these mineral constituents may be either of *mineral* or of *organic* origin.

(1.) The material of *organic origin* is that derived from the remains of plants or animals. Of this origin is the material of nearly all the great limestone formations; for the substance of the rock was made from shells, corals, or crinoids, triturated into a calcareous earth by the sea (if not too minute to require it), and consolidated, just as corals are now ground up and worked into great coral reef-rocks in the West Indies and Pacific. In other cases, only a small part of a rock is organic, the rest being of mineral origin. Such rocks usually contain distinct remains of the shells or corals that have contributed to their formation: these relics, whether of plants or animals, are called *fossils* or *organic remains*, and the rocks are said to be *fossiliferous*. They are also often called *petrifactions*, though not always really petrified.

(2.) The material of *mineral origin* includes all that is not directly of organic origin, — all the sand, clay, gravel, etc., derived from the trituration or wear of other rocks; the material from chemical deposition, like some limestones, or from volcanic action, like lavas and trap or basalt.

But, whether organic or mineral in origin, the material, when in the rock, though sometimes under the form of fossils, is almost solely in the *mineral* condition. The topics for consideration in connection with this subject are, then, the following: —

1. The elements constituting rocks.
2. The mineral material constituting rocks.
3. The kinds of rocks.

1. ELEMENTS CONSTITUTING ROCKS.

General considerations. — In the foundation-structure of the globe, firmness and durability are necessarily prime qualities, while in living structures, instability and unceasing change are as marked characteristics.

These *diverse* qualities of the organic and inorganic world proceed partly from the intrinsic qualities of the elements concerned in each.

In the inorganic kingdom (which includes minerals and rocks), —

(1.) The elements which combine with oxygen to become the essential ingredients of rocks, are mainly hard and refractory substances: as, for example, *silicon*, the basis of quartz; *aluminum*, the basis of clay; *magnesium*, the basis of magnesia.

(2.) Or, if unstable or combustible elements, they are put into stable conditions by combination with oxygen. Thus, carbon, which we handle and burn in charcoal, becomes *burnt* carbon (that is, carbon combined with oxygen, forming carbonic acid) before it enters into the constitution of rocks. So all minerals are made of *burnt* compounds, — called *burnt* because ordinary combustion consists in union with oxygen and the production of stable oxyds. They are therefore dead or inert in ordinary circumstances, and hence fit for *dead* nature.

In organic nature (or, plants and animals) on the contrary, —

(1.) The essential elements are combustible substances, and mostly gases, — oxygen combined with carbon and hydrogen forming plants, and oxygen with carbon, hydrogen, and nitrogen forming animal substances. Nitrogen is present only very sparingly in plants.

(2.) The elements in living beings, moreover, are not saturated with oxygen: they are therefore in an unstable and constrained condition. Both from their nature and their peculiar condition, they have a strong tendency to take oxygen from the atmosphere with which they are

bathed or penetrated, and combine with it. This state of strong attraction for oxygen — for something not in the structure itself — is the source of activity in the vital functions, and involves unceasing change as the means of existence and growth, and a final dissolution of the structure at the cessation of life.

Hence, strength and durability belong to the basement-material of the globe, and instability to living structures.

But inorganic nature is still not without change. For there are diversities of attraction among the elements and their compounds. The changes are, however, slow, and not essential to the existence of the compounds. The processes of solution, of oxidation and deoxidation, and other chemical interactions, changes by heat, and other molecular and mechanical influences, give a degree of activity even to the world of rocks. But this topic belongs to the dynamics and chemistry of geology.

Characteristic elements. — The elements most important in rocks are the following: —

(1.) *Oxygen.* — Oxygen is a constituent of all rocks, and composes about one-half by weight of the earth's crust.

Sand is, by weight, more than half oxygen; quartz, the principal material of sand, is about 53 per cent. oxygen; common limestone, 48 per cent.; alumina, nearly 47 per cent.; feldspar, 46 to 50 per cent.; common clay, 50 per cent.: and thus it is with the various ordinary rocks. Besides, the atmosphere contains 23 per cent. of oxygen, and water — the material of the oceans, lakes, and rivers — 89 per cent.

(2.) *Silicon.* — After oxygen, silicon is the element next in abundance, constituting at least a fourth of the earth's crust. It is unknown in nature in the pure state; but, combined with oxygen, and thus forming silica, or quartz, it is common everywhere. This silica is an acid, although tasteless; and its combinations with alumina, magnesia, lime, and other bases (called *silicates*), along with quartz, are the principal constituents of all rocks except limestones. Silica constitutes about 60 per cent. of these ingredients; and, including the limestones, 50 per cent. of all rocks. Silicon has therefore the same prominent place in the mineral kingdom as carbon in the organic.

Granyte and gneiss are nearly three-fourths silica, — half of it as pure quartz, and the rest as silicates; mica schist and roofing-slate are about two-thirds silica; trap and lavas are one-half; porphyry, two-thirds; sandstones are sometimes all silica, and usually at least four-fifths.

Silica is especially adapted for this eminent place among the architectural materials of the globe by its great hardness, its insolubility and resistance to chemical and atmospheric agents, and its infusibility. As it withstands better than other common minerals the wear of the waves or streams, besides being very abundant, it is the prevailing

constituent of sands, and of the movable material of the earth's surface, as well as of many stratified rocks; for the other ingredients are worn to the finest powder by the quartz, under the constant trituration, so as to be drifted away by the lightest currents. It is also fitted for its prominent place by its readiness in forming siliceous compounds and the durability of these silicates. Moreover, although infusible and insoluble alone, when mixed with different oxyds it melts and forms glass; or, if but a trace of alkali be contained in waters, those waters, if heated, have the power of dissolving it; and, thus dissolved, it may be spread widely, either to enter into new combinations, or to fill with quartz any fissures and cavities among the rocks, thereby making veins and acting as a general cement and solidifier.

Its applications in world-making are, therefore, exceedingly various. In all, its action is to make stable and solid.

(3.) *Aluminum.* — Aluminum is a white metal, between tin and iron in many of its qualities, but as light as chalk. Combined with oxygen, it forms alumina (Al^2O^3), the basis of clay. This alumina constitutes the gem sapphire, which is next in hardness to the diamond, and of extreme infusibility and insolubility. It is the most common base in the silicates, thereby contributing to a large part of all siliceous minerals, and therefore of all rocks. With quartz, these compounds (aluminous silicates) make granyte, gneiss, mica schist, syenyte, and some sandstones, and alone they form trachyte and some other igneous rocks. Nearly all the rocks, except limestones and many sandstones, are literally ore-beds of the metal aluminum.

(4.) *Magnesium.* — This metal combined with oxygen forms magnesia (MgO), a very refractory and insoluble base, producing with silica a series of durable silicates, very widely distributed: some are quite hard, as hornblende and pyroxene; others are soft, and have a greasy feel, like talc, soapstone, and serpentine.

Unlike alumina, magnesia unites with carbonic acid, forming *carbonate of magnesia* (MgO, CO^2).

(5.) *Calcium.* — The oxyd of the metal calcium is common quicklime. Like magnesia, it enters into various silicates; and it also forms a carbonate, *carbonate of lime* (CaO,CO^2), and this carbonate is the material of limestones. Moreover, with sulphuric acid and water, it forms *sulphate of lime*, or gypsum.

The peculiar position of lime in the system of nature is that of a medium between the organic and inorganic world. Carbonate of lime is soluble in water, when a little carbonic acid is present in solution; and both this and the sulphate are found in river, marine, and well waters. It is made into shells, corals, and partly into bone, by animals, and then turned over to the inorganic world to make rocks.

Lime is, therefore, the medium by which organic beings aid in the inorganic progress of the globe, as above stated: far the greater part of limestones have been made through the agency of life, either vegetable or animal.

Lime also unites with phosphoric acid, forming *phosphate of lime*, the essential material of bone, and a constituent also of other animal tissues. Like the carbonate, this phosphate is afterward contributed to the rock-material of the globe, and is one source of mineral phosphates.

(6.) (7.) *Potassium* and *Sodium*. — Potassium is the metallic base of *potash*, and sodium of *soda*. The alkalies potash and soda, besides some other oxyds, form glass or fusible compounds with silica; and this fact indicates one of their special functions in the earth's structure. Silica, alumina, and the pure silicates of alumina are quite infusible; but, by the addition of the alkalies, or the oxyds of iron or lime, fusible compounds are formed. And, as the earth's early history was one of universal fusion, the alkalies performed an important part in the process, as they have since in all igneous operations. Feldspars, which are found in all igneous rocks, are silicates of alumina with potash, soda, or lime. A heated solution of potash or soda will also dissolve silica, and so aid in distributing quartz or making silicates.

Sodium is likewise the basis of common salt in sea-water.

(8.) *Iron*. — Iron combines with oxygen and forms two compounds, a protoxyd FeO, and a sesquioxyd Fe^2O^3, and one or the other occurs, along with alumina, magnesia, or lime, in many silicates, which are mostly fusible. Silica and magnesia or lime with protoxyd of iron make part of the very abundant mineral *hornblende*, found in syenyte, hornblendic slate, etc.; and also the equally common *pyroxene*, characteristic of the heavy, dark-colored lavas.

(9.) *Carbon*. — Carbon is well known in three different states, — that of the diamond, the hardest of known substances, that of graphite or black lead, and that of charcoal. Combined with oxygen, it forms carbonic acid (CO^2); and carbonic acid combined with lime makes carbonate of lime, or common limestone; with magnesia, carbonate of magnesia, or magnesite; with protoxyd of iron, carbonate of iron or siderite; etc.

Carbonic acid exists in the atmosphere, constituting ordinarily about one part in twenty-five hundred by weight.

This acid is the only acid in the mineral kingdom, in addition to silica, which enters very largely into the constitution of rocks; and, while silica has alumina and other sesquioxyds wholly to itself, carbonic acid shares with it in the magnesia, lime, and alkalies, that is, in all the protoxyds. Carbon, we have said, performs as fundamental a part in living nature as silicon in dead nature; and it is mainly through living beings that it reaches the mineral kingdom and forms limestones and coal-beds. The deposits

of carbonate of lime that have been produced by direct chemical deposition from the waters of the globe are small compared with those made of organic remains of plants or animals.

The *nine* elements above mentioned, *oxygen, silicon, aluminum, magnesium, calcium, potassium, sodium, iron,* and *carbon,* are the prominent constituents of rocks, making up 977-1000ths of the whole.

(10.) *Sulphur.* — Sulphur exists native in volcanic and some other regions. In combination with various minerals, it forms ores called *sulphids,* as sulphid of iron, or pyrite, sulphid of copper, sulphid of silver. But these sulphids do not constitute properly beds of rock; although two of them, pyrite and pyrrhotite, are very abundant. Sulphur forms with oxygen two acids, *sulphurous* acid (SO^2), and *sulphuric* acid (SO^3). Sulphuric acid united with lime makes sulphate of lime, or gypsum, which sometimes occurs in extensive beds. There are also many other sulphates, but none are true rock-constituents.

(11.) *Hydrogen* with oxygen constitutes water; and water, besides being abundant over the earth's surface, is a constituent of many minerals. Gypsum contains 21 per cent., serpentine 13 per cent., talc 5 per cent.

(12.) *Chlorine* with sodium forms chlorid of sodium, or common salt, which is found in large beds, and also dissolved in sea-water and brine-springs.

(13.) *Nitrogen* is an ingredient of the atmosphere, — making 77 per cent. of it. With oxygen it forms nitric acid (NO^5); but no nitrates enter prominently into the structure of rocks.

The thirteen elements mentioned are all that occur as important rock-constituents. Others require attention in discussing topics connected with chemical geology, in which department the profoundest knowledge of chemistry and mineralogy is none too much. But in a general review of rocks only these thirteen need be considered.

2. MINERALS CONSTITUTING ROCKS.

The minerals which are the principal constituents of rocks are the following: —

1. *Those containing silica:* as quartz; the feldspars; the micas: hornblende; pyroxene; talc; serpentine; chlorite.

2. *Carbonates:* as carbonate of lime, or calcite; carbonate of lime and magnesia, or dolomite.

3. *Sulphates:* as sulphate of lime or gypsum.

Th especial characteristics of these, and of other less frequent mineral constituents, will be learned from a Manual of Mineralogy. The following are the prominent characters of the most common kinds:[1] —

(1.) Quartz. — Quartz is the first in importance. It occurs in crystals, like Figs. 32 and 33; also massive, with a glassy lustre. It is too hard to be scratched with a knife. It varies in color from white or

[1] The ordinary characters by which minerals are distinguished are — relative *hardness,* as ascertained by a file, or the point of a knife, or by scratching one mineral with another; *specific gravity,* or relative weight; *lustre* and *color; crystalline form; cleavage* (cleavage being a facility of cleaving or breaking in some one or more directions, and affording even, lustrous surfaces, as in *mica, gypsum, feldspar*); *fusibility; chemical composition.*

colorless to black, and in transparency from transparent quartz to opaque. It has *no cleavage,* — that is, it breaks as easily in one direction as another, like glass. Specific gravity, 2·65. Before the blowpipe it is infusible, unless heated with soda, when it fuses easily to a glass. Clear kinds are called *limpid* quartz; violet crystals are the *amethyst;* compact translucent, with the colors in bands or clouds, *agate;* the same, without bands or clouds, *chalcedony;* massive, of dark and dull color, with the edges translucent, *flint;* the same, with a splintery fracture, *hornstone;* the same, more opaque, *lydianstone* or *basanite;* the same, of a dull red, yellow, or brown color, and opaque, *jasper;* in aggregated grains, *sandstone* or *quartzyte;* in loose, incoherent grains, *ordinary sand.*

Fig. 32.

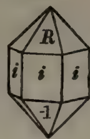
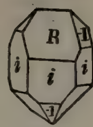


Fig. 33.



Silica also occurs in another state, constituting *opal,* a well-known mineral. In this state it is never crystallized, and is easily dissolved in a heated solution of potash, while quartz is so with difficulty. Opal usually contains some water, and is a little softer than quartz. Silica exists also in a third state called *tridymite,* having the specific gravity 2·3. Unlike quartz, it crystallizes in hexagonal tables.

(2.) FELDSPAR. — The feldspars are next in abundance to quartz. They have a lustre nearly like quartz, but often somewhat pearly on smooth faces; are very nearly as hard as quartz, with about the same specific gravity (2·4–2·6); and in general have light colors, mostly white or flesh-colored, though occasionally dark gray, brownish, or green. They differ from quartz in having a perfect cleavage in one direction, yielding under the hammer a smooth lustrous surface, and another nearly as perfect in a second direction, inclined 84° to 90° to the first; also in being fusible before the blowpipe, though not easily so; also in composition, the feldspars consisting of silica combined with alumina and an alkali — this alkali being either potash, soda, or lime, or two or all of these combined.

(3.) MICA. — The transparent mineral often used in the doors of stoves and lanterns is *mica,* often wrongly called *isinglass.* It is remarkable for splitting easily into very thin elastic leaves or scales, — even thinner than paper, — and for its brilliant lustre. It occurs colorless to brown, green, reddish and black; and either in small scales disseminated through rocks, — as in granyte — or in plates a yard in diameter. Consists of silica and alumina with either potash, magnesia, or iron, and some other ingredients. Fluorine is sometimes present. It is of several kinds, which differ in composition and optical characters more than in appearance. Some of the varieties resemble crystallized talc and chlorite, from which they differ in being elastic (unless weathered).

Feldspar and mica each include a number of distinct kinds or species.

Under *feldspar*, these species differ in the proportion of silica (the acid) to the other ingredients (bases), and in the particular alkali (potash, soda or lime) predominant. The more important kinds are as follows, — (1) *Orthoclase*, or common feldspar, a *potash*-feldspar; silica about 64 to 66 per cent. of the whole, the oxygen ratio of the silica to the bases being 3 to 1; the cleavages make a right angle with one another, whence the name, signifying *cleaving at a right angle.* Figures 34, 35 represent crystals of this species. Cleavage takes place parallel to the faces *O* and *ii*.

Fig. 34.

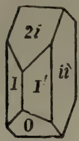
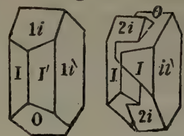


Fig. 35.



In the following kinds the cleavages make an oblique angle with one another, of 84°–87°, and hence they are sometimes called *anorthic feldspars.*

(2.) *Albite*, a *soda* feldspar; O. ratio of the silica to the bases 3 to 1, as in orthoclase. (3.) *Oligoclase*, a *soda-lime* feldspar, the soda predominating ; O. ratio of the silica to the bases $2\frac{1}{4}$ to 1. (4.) *Labradorite*, a *lime-soda* feldspar, often iridescent; O. ratio of the silica to the bases $1\frac{1}{2}$ to 1. (5.) *Anorthite*, a *lime* feldspar; O. ratio of the silica to the bases 1 : 1. Orthoclase and Albite are eminently *acidic* feldspars, and Labradorite and Anorthite as eminently *basic. Andesite* is another feldspar, between oligoclase and labradorite in composition.

Under *mica*, the more common kinds are the following : (1.) *Muscovite*, or potash mica (muscovy glass, of early mineralogy) usually whitish to brown in color. (2.) *Biotite* (named after Biot, the French physician), a magnesia-iron mica, usually black. (3.) *Lepidomelane*, an iron-mica, not elastic, of black color. (4.) *Phlogopite*, a magnesia-mica of light brown to white color, common in connection with crystalline limestones. (5, 6.) *Margarodite* and *Damourite*, micas like muscovite in composition, except the presence of some water (whence called *hydromicas*); also like muscovite in color, but more pearly in lustre, and less elastic; often look and feel like talc, and the slaty rocks consisting largelv of them have been often called *talcose slates*, because soapy to the touch, when really *hydromica slates.* (7.) *Paragonite* is a hydrous *soda* mica.

HORNBLENDE (often called AMPHIBOLE). — The most common kind in rocks is an iron-bearing variety, in black cleavable grains or oblong black prisms, cleaving longitudinally in two directions inclined to one another 124° 30′. It occurs, also, in distinct prisms of this angle, and of all colors from black to green and white. Figures 36, 37, and 38 represent these common forms, and 39 tufts of crystals as they often appear in some rocks. The green kind is called *actinolite*, — a common form of its crystals is shown in Fig. 38 ; the white (a kind common in crystalline limestones, and containing much lime), *tremolite.*

Fig. 36.

Fig. 37.

Fig. 38.

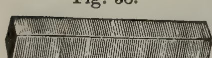
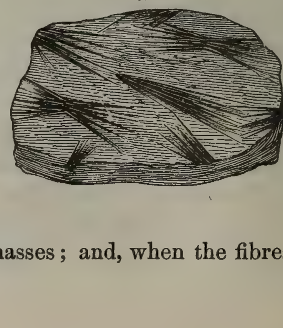


Fig. 39.



The mineral is common in fibrous masses; and, when the fibres are as

fine as flax, the mineral is called *asbestus*. The principal constituents of the mineral are silica, magnesia, oxyd of iron, and lime; but, unlike the feldspars, it contains little or no alumina.

PYROXENE (including Augite). Like hornblende in most of its characters, its variety of colors and its chemical composition. But the crystals, as in the annexed figures, 40, 41, instead of being prisms of 124° 30′, are prisms of 87° 5′ or nearly (angle I on I), and are often eight-sided from the truncation of the four edges, as in Fig. 41. Black and dark-green pyroxene in short crystals is called Augite; it is an iron-bearing kind, and is common in igneous rocks.

Fig. 40.

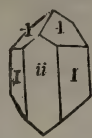


Fig. 41.

TALC, SERPENTINE, CHLORITE. Talc and serpentine are silicates of magnesia containing water. They are soft minerals, talc being easily impressed with the nail, and serpentine easily cut with a knife; and both, but especially the talc, feeling greasy in the fingers.

Talc occurs in broad, pale green or whitish plates, looking like mica; but the plates are much softer, and have no elasticity. Common *steatite* or *soapstone* is nothing but a massive talc. Talc consists of silica 62·12, magnesia 32·94, water 4·94 = 100.

Serpentine is usually compact massive, not granular at all, of a dark-green color, but varying from pale green to greenish black. There is a fibrous variety occurring in seams in massive serpentine, which is called chrysotile. The species contains silica 43·6, magnesia 43·4, water 13·0 = 100.

Chlorite occurs of dark green color, sometimes thin foliated like mica, but inelastic, oftener granular massive. It is a very soft mineral, being in hardness between talc and serpentine. Besides silica, magnesia and water, it contains alumina and oxyd of iron.

Among the *Carbonates*, the most common is CALCITE, or carbonate of lime, one of the most universal of minerals. It is the ingredient of a very large part of the limestones of the world, and these include the various true marbles. When free from impurities, it consists of carbonic acid 44·0, lime 56·0 = 100. It is easily scratched with the point of a knife-blade; and, when dropped in powder into muriatic (chlorhydric) acid diluted with one half water, it effervesces strongly, giving off carbonic acid. The following are some of the forms it presents when crystallized. It cleaves alike in three directions making the angle 105° 5′ with one another, and the resulting form, Fig. 42 A, is called a rhombohedron. When crystallized, calcite is often transparent and colorless. But the mineral occurs of various colors from white to black, and the massive kinds from translucent to opaque.

DOLOMITE, or carbonate of lime and magnesia, resembles calcite so

closely that the two cannot often be distinguished except by chemical means. Like calcite, it constitutes many limestone strata, both massive

Fig. 42.

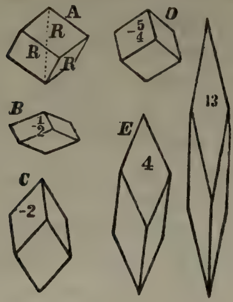
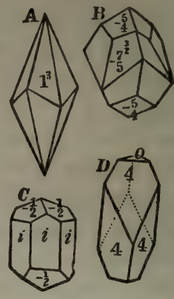


Fig. 43.



and crystallized. When dropped in powder into dilute muriatic acid, it effervesces very feebly, if at all, in the cold; but, on heating the acid, there is a brisk effervescence produced. The angles between its cleavage faces is 106° 15′, and this, with crystallized specimens, is an important means of distinction. Composition, carbonate of lime 54·4, carbonate of magnesia 45·6 = 100.

Among *sulphates*, the only very common species is Gypsum. It is a very soft mineral, one of the few that may be easily impressed with the teeth, and without producing a grating sensation. It is often massive and very fine granular, and of various colors from white to black; the white is common *alabaster*. It also occurs in crystals and crystalline masses. Figures 44, 45 give two of the forms of the crystals.

Fig. 44.

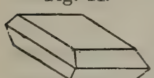
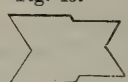


Fig. 45.



It cleaves in broad pearly plates or folia, which look like mica, but are softer and not elastic. Unlike limestone and other minerals, a little heat reduces it to powder, making the common *plaster of paris* of the shops. It consists of sulphuric acid 46·51, lime 32·56, water 20·93 = 100.

Sulphate of lime also occurs without water, and is then called *anhydrite*; the crystallization is very different, cleavage affording rectangular blocks or plates.

Besides these very abundant rock-making species, there are the following of quite common occurrence.

Anhydrous Silicates. *Nephelite*, a colorless to grayish-green and greenish mineral (also of other shades), related somewhat to the feldspars, and having the place of a feldspar in some igneous rocks. Its crystals are hexagonal prisms. Silica, alumina, soda and potash are the principal constituents.

Leucite. A white or grayish-white mineral occurring in 24-sided crystals resembling Fig. 47; it takes the place of a feldspar in igneous rocks, at Vesuvius and some other European localities. Silica, alumina, and potash are its constituents.

Chrysolite (called also *Olivine*), occurring in green glassy grains or crystals, and common in many basaltic rocks. Consists of silica, magnesia, and iron.

Garnet, in crystals of the forms in Figs. 46, 47, disseminated in various crystalline

Fig. 46.

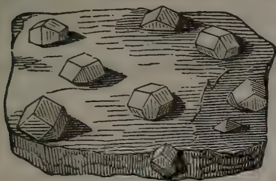
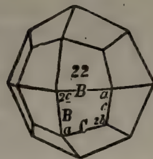


Fig. 47.

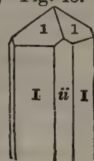


rocks; colors usually red to black; rarely green. Consists of silica, alumina, magnesia, lime, and iron.

Epidote, in yellowish-green prismatic crystals and masses; also of brown and gray-white colors. Constituents as in garnet.

Scapolite, in four-square and eight-sided erect prisms, white to gray, and sometimes greenish or reddish. One of the forms of its crystals is shown in Fig. 48. Constituents, silica, alumina, lime, and usually some soda.

Fig. 48.



Andalusite, in whitish, grayish, prismatic crystals, nearly square, imbedded in slaty

Fig. 49.

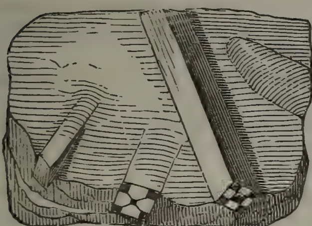
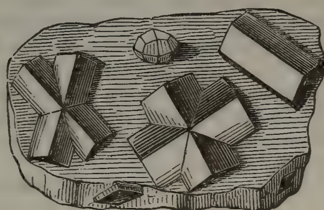


Fig. 50.



rocks. Crystals having the interior tessellated with black, as in figure 49, are called *Chiastolite*. Composition: silica 37·0, alumina 63·0.

Staurolite, in rhombic prisms of 129° 20′, imbedded in slaty rocks. Usual colors, brown to black. The crystals are often crossed as in Fig. 50, and hence the name, from the Greek for *cross*. Composition: silica 29·3, alumina 53·5, sesquioxyd of iron 17·2 = 100.

Cyanite (spelt also Kyanite), in thin and often long-bladed crystals of sky-blue to white color. Same composition as Andalusite. Named from the Greek for *blue*.

Tourmaline. — Usually in three-sided or six-sided black crystals, showing no distinct cleavage, and thus differing from hornblende. Figs. 51, 52 show two of the forms; and

Fig. 51.

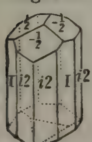


Fig. 52.

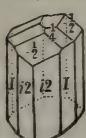
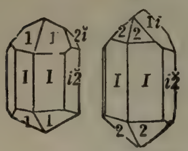


Fig. 53.

Fig. 53, the appearance of the crystals in the rock (often quartz). Besides black, there are also brown, green, red and white tourmalines. Constituents: silica, alumina, magnesia, with fluorine and some *boracic acid.*

Fig. 54. Fig. 55.



Topaz, in rhombic prisms of 124° 19′, remarkable for cleaving with ease and brilliancy parallel to the base of the prism. Colors, yellowish to white; also brown. Two of the forms of its crystals are shown in figures 54, 55.

Beryl, in six-sided prisms, usually pale green, but deep green in the variety emerald.

All the above anhydrous minerals are too hard to be scratched with a file. The following contain water, and are softer.

2. Hydrous Silicates. — Besides the hydrous micas, there are the common species:

Agalmatolite, a compact mineral, soapy to the touch, often resembling a compact soapstone. Like serpentine and massive pyrophyllite, it is often cut into images in China. Consists of silica, alumina, potash, and water.

Pyrophyllite. — A mineral resembling talc in color, cleavage, and soapy feel, when crystallized, and like some fine-grained soapstone when massive. Consists of silica, alumina, and water. It differs from talc in containing alumina in place of magnesia.

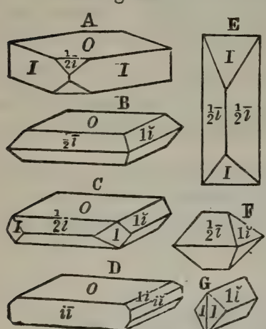
Glauconite or *Green Earth*, the material of the New Jersey marl, or Green sand of the Cretaceous and other rocks. It is a soft, dark or light green silicate of alumina, iron, and potash, with water.

Clay is not ordinarily a simple mineral, but a mixture of powdered feldspar and quartz. But the soft clay, soapy to the touch, found in some places, is the species *kaolinite*, or the material of kaolin — the clay which is used in the manufacture of porcelain. It is a result of the decomposition of some kind of feldspar containing potash or soda, and consists of silica 41·5, alumina 34·4, and water 24·1 = 100.

3. Carbonates, Sulphates, Phosphates, and Fluorids. — Among these minerals, there are a few species common enough to be here enumerated.

Siderite or *Carbonate of Iron*, like calcite in cleavage, and white or grayish white, but changing readily to a brown color on exposure, and finally to the hydrous oxyd of iron called limonite.

Fig. 56.



Magnesite, or *Carbonate of Magnesia*, white and like calcite in cleavage, but often occurring massive and looking like porcelain biscuit.

For other related carbonates, reference must be made to the Mineralogy.

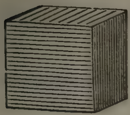
Barite, or Heavy Spar, is a sulphate of baryta. It occurs in tabular crystals, some of the forms of which are given in Fig. 56. It is remarkable for its high specific gravity, whence the name, from the Greek for *weight.* It contains sulphuric acid 34·33, baryta 65·67 = 100.

Apatite is a *phosphate* of lime. It commonly occurs in six-sided prisms, greenish in color, and looking like beryl, from which it differs in being easily scratched with a knife. Its crystals are sometimes transparent and colorless, or bluish, and occasionally brown.

Fluorite, or *Fluor Spar*, a fluorid of calcium. Its crystals are cubes, octahedrons and other related forms. All of them cleave easily in four directions, parallel to the faces of the regular octahedron, the faces of cleavage making angles with one another of 109° 28′. It is often granular-massive. It is easily scratched with a file. Its colors are clear purple, yellow, blue, often white, and of other shades. When powdered and thrown on a shovel heated nearly to redness, it phosphoresces brightly. Composition: fluorine 48·7, calcium 51·3.

4. THE METAL-BEARING MINERALS OR ORES, COMMON IN ROCKS. — *Pyrite*, a compound of sulphur and iron, in the proportion of 53·3 to 46·7, and having a very pale brass-like color, much less yellow than copper pyrites; it is unlike the latter also in striking fire with a steel, whence the name, from the Greek for *fire*. Occurs often in cubes like Fig. 57. The striæ of the adjoining surfaces, when any are present, are at right angles with one another. Another compound of sulphur and iron, called *pyrrhotite*, contains 40 per cent. of sulphur to 60 of iron, and is soft like the following species, but is of a pale bronze color.

Fig. 57.



Chalcopyrite, or *Copper Pyrites*. — A compound of sulphur, copper, and iron, of a deep brass-yellow color, easily scratched, and yielding a dark green powder (and thus distinguished from pyrite); and when a solution is made with dilute nitric acid, a blade of iron put into it becomes red from a coating of copper.

Galenite, or *Galena*, the most common ore of lead. A compound of sulphur and lead in the proportion 13·4 to 86·6, of a lead-gray color, soft and brittle. It occurs in cubes, dodecahedrons and other forms, and cleaves easily into cubes.

Blende (sphalerite), a compound of sulphur and zinc, in the proportion of 33 to 67; of resin-yellow and brown colors, also black, and sometimes looking metallic, but giving a whitish powder. Crystalline masses cleave easily, yielding rhombic dodecahedrons.

Hematite or *Specular Iron*, *Magnetite*, and *Limonite* are the more common oxyds of iron occurring as ores.

Hematite, or specular iron ore (Fe^2O^3), is often in dark steel-gray crystals or masses, and also in deep-red earthy masses, and has a red powder. *Magnetite* (Fe^3O^4) is in dark iron-gray crystals (often octahedrons or dodecahedrons), and also massive, and has a black powder. *Limonite* ($2Fe^2O^3+3H^2O$) occurs black and also in brownish-yellow earthy masses, and is distinguished by a brownish yellow powder. *Menaccanite*, or *Titanic iron*, is an ore like hematite in its crystals, but blacker in color, and black in its powder. It contains titanium as well as iron and oxygen.

Graphite, called also *Plumbago*, and *Black Lead* (the material of lead pencils), looks like a metallic substance; but it is simply carbon, neither lead nor iron occurring in the pure mineral.

7. *Materials of organic origin.*

The materials of organic origin — that is, those derived from plants or animals — may be arranged in *four* groups.

(1.) The *calcareous*, or those of which limestones have been formed: namely, corals, corallines, shells, crinoids, etc. The specific gravity of corals is 2·4–2·82; of shells, 2·4–2·86, — the highest from a Chama (Silliman Jr.).

(2.) The *siliceous*, or those which have contributed to the silica of rocks, and may have originated flint: namely, (*a*) the microscopic siliceous shields of the infusoria called *Diatoms* (p. 135), which are now regarded as plants; (*b*) the microscopic siliceous spicula of Sponges (p. 132); (*c*) the microscopic siliceous shells of *Polycystines*, a kind of minute animal life; (*d*) the minute teeth of Mollusks.

(3.) The *phosphatic*, or those which have contributed phosphates, especially phosphate of lime; as *bones*, *excrements*, the shells of *Lingulæ*, *Discinæ*, and a few other mollusks, and those of crustaceans and insects, as well as ordinary animal tissues; also the stems, leaves, and fruit of plants, — especially the edible grains. Fossil excrements are

called *coprolites ;* when in large accumulations (as sometimes made by birds or bats), *guano.*

The remains of animals have also afforded traces of fluorine.

(4.) The *carbonaceous*, or those which have afforded coal, mineral oil, and resin, as plants.

Besides these, there is a fifth kind, though of little importance geologically, viz., the animal tissues themselves. Only in a few cases do any of these tissues remain in fossils, except in some groups belonging to the later geological epochs. These tissues contain traces of phosphates and fluorids which they have contributed to the muds of which rocks have been made.

(1.) CALCAREOUS. — The following are a few analyses: 1 and 2, corals, *Madrepora palmata*, and *Oculina arbuscula* by S. P. Sharples (Am. Jour. Sci., III. i. 168) ; 3, shell of a *Terebratula*, by the same: —

	Madrepora.	Oculina.	Terebratula.	Oyster-shell.
Carbonate of lime	97·19	95·37	98·39	93·9
Phosphate of lime	0·78	0·84 }	0·61	0·5
Sulphate of lime	–	– }	–	1·4
Water and organic matters .	2·81	3·79 }	1·00	3·9
Carbonate of magnesia . .	–	–	–	0·3

In many shells, the inner pearly layer consists of carbonate of lime in the condition of aragonite; while the outer (or the whole, if no part is pearly) is usually common carbonate of lime, or calcite. The spines of fossil *Echini* are calcite.

In corals of the genus *Millepora*, according to Damour, there is, besides carbonate of lime, some carbonate of magnesia, amounting in one species to 19 per cent., while but little in others. These corals have been shown by Agassiz to be the secretions of *Acalephs*, and not of ordinary polyps. Forchhammer found 6·36 per cent. of carbonate of magnesia in the *Isis nobilis*, and 2·1 per cent. in the *Corallium nobile*, or "precious coral" of the Mediterranean.

The *Nullipores* and *Corallines* are vegetation having the power of secreting lime, like the coral animals. The shells of *Rhizopods* (called also *Polythalamia* and *Foraminifera*) are calcareous.

The shell of a lobster (*Palinurus*) afforded Fremy, carbonate of lime, 49·0, phosphate of lime, 6·7, organic substance, 44·3.

(2.) SILICEOUS. — The organic silica is, in part at least, in that condition characterizing opal (p. 53). This is the case with the siliceous spicula of sponges and with diatoms.

(3.) PHOSPHATIC. — Analyses of *bones:* 1, 2, human bones, according to Frerichs; 3, fish (Haddock), according to Duménil; 4, shark (*Squalus cornubicus*), according to Marchand; 5, *fossil bear*, id.; 6, shell of *Lingula ovalis*, Hunt.

	1.	2.	3.	4.	5.	6.
Phosphate of lime	50·24	59·50	55·26	32·46	62·11	85·79
Carbonate of lime	11·70	9·46	6·16 }	4·44	13·24	11·75
Sulphate of lime	–	–	– }		12·25	–
Organic substance	38·22	30·94	37·63	58·07	4·20	–
Traces of soda, etc.	–	–	1·22	3·80	–	–
Fluorid of calcium	–	–	–	1·20	2·12	–
Phosphate of magnesia . . .	–	–	–	1·03	0·50	2·80

In No. 4, a little silica and alumina are included with the fluorid. No. 5 contains also

silica 2·12, and oxyds of iron and manganese, etc., 3·46. In No. 6, the 2·80 is magnesia.

The *enamel* of teeth contains 85 to 90 per cent. of phosphate of lime, 2 to 5 of carbonate of lime, and 5 to 10 of organic matters. The shells of a fossil *Obolus* afforded Kupffer the composition nearly of a fluor-apatite (Am. Jour. Sci., III. vi. 146).

Fish-scales from a *Lepidosteus* afforded Fremy 40 per cent. of organic substance, 51·8 of phosphate of lime, 7·6 of phosphate of magnesia, and 4·0 of carbonate of lime. Other fish-scales contained but a trace of the magnesia-phosphate and more of organic matters.

The ashes of ordinary meadow-grass afford 8 per cent. of phosphoric acid; of rye straw, 4 per cent.; of clover, 18 per cent.; of wheat and rye, 50 per cent.; of peas and beans, 33–38 per cent.; of sea-weeds of the genus *Fucus*, 1·2 to 4 per cent.; of the genus *Laminaria*, 3·4 to 5 per cent. (Schweitzer); of the species *Iridea edulis*, 11·4 per cent. (Forchhammer).

Phosphatic nodules, possibly coprolitic, in the Lower Silurian rocks of Canada (on river Ouelle), afforded T. S. Hunt (see Am. Jour. Sci., II. xv. and xvii.), in one case, phosphate of lime, 40·34, carbonate of lime, with fluorid, 5·14, carbonate of magnesia 9·70, peroxyd of iron, with a little alumina, 12·62, sand 25·44, moisture 2·13 = 95·37. In a hollow cylindrical body from the same region, there were 67·53 per cent. of phosphate.

Analyses of Coprolites (*Fossil Excrements*). — Nos. 1 and 2 by Gregory and Walker; 3 and 4 by Connell; 5 by Quadrat; 6 by Rochleder (a coprolite from the Permian).

	1. Burdie-house.	2. Fife-shire.	3. Burdie-house.	4. Burdie-house.	5. Kosch-titz.	6. Oberlan-genau.
Phosphate of lime	9·58	63·60	85·08	83·31	50·89	15·25
Carbonate of lime	61·00	24·25	10·78	15·11	32·22	4·57
Silica	4·13	trace	0·34	0·29	0·14	–
Organic material		3·38	3·95	1·47	7·38	74·03
Carbonate of magnesia	13·57	2·89	–	–	–	2·75
Sesquioxyd of iron	6·40	trace	–	–	2·08	–
Alumina	–	–	–	–	6·42	–
Water	5·33	3·33	–	–	–	–
Lime of organic part	–	–	–	–	–	1·44
Chlorid of sodium	–	–	–	–	–	1·96
	100·01	97·45	100·15	100·18	99·13	100·00

(4.) Carbonaceous. — *Mineral coal* consists mainly of carbon, with some hydrogen and oxygen, traces of nitrogen, and more or less of earthy impurities called the *ash*. The hydrogen and oxygen are supposed to be combined with part or all of the carbon, so that most coal consists of oxygenated hydrocarbons. When heated, they usually afford much volatile matter, although containing none, this arising from the decomposition by heat of some of the hydrocarbons present: the volatile matter is mostly hydrocarbon oils (some kind of petroleum) or gas, with a little water. The dry porous carbon left behind is called *coke*. Coals affording much volatile matter, and burning with a yellow flame, are said to be *bituminous*; and those affording little, and burning with a a pale blue flame, *non-bituminous*. The varieties are: —

A. *Anthracite*. — Non-bituminous, or nearly so. A hard, lustrous coal, breaking with a conchoidal fracture and clean surface, and burning with very little flame, as the coal of Lehigh, Wyoming, and other places of central Pennsylvania, also that of Rhode Island.

B. *Bituminous coal*. — Bituminous. Softer than anthracite, less lustrous, often looking a little pitchy. The amount of volatile substances yielded varies from 10 to 60 per cent.

a. Brown coal is black or brownish black coal, containing much oxygen, and occurring in Mesozoic and more modern deposits. It is often called *Lignite*. True lignite re-

tains the form and structure of the original wood, and burns with an empyreumatic odor. *Jet* is a compact black lustrous lignite. *Peat* is imperfect coal, or partially carbonized vegetable material, from modern swamps.

On coals, see further, page 314; also, author's Mineralogy, pp. 753–760, on Mineral oils, pp. 723–730, on Asphalt, etc., pp. 751–753.

Fossils. — From the above account of the composition of the hard parts of organic beings, their influence on the composition of rocks is readily inferred.

But the fossils themselves seldom retain completely, even in the case of such stony secretions as shells and corals, their original constitution. There is usually a loss of the organic matter. There is often a further change of the carbonate of lime into a new molecular condition, manifest in the fact that the fossil has the oblique cleavage of calcite; and in this change there is a loss of part or all of the phosphate or fluorid. There is sometimes, again, a change to dolomite, in which the carbonate of lime becomes a carbonate of lime and magnesia. In other cases, of very common occurrence, all the fossils of a rock, whether it be limestone or sandstone, are changed to silica (quartz) by a silicifying process. Silicified trunks of trees, as well as shells, occur in rocks of various geological ages. In some cases, fossils have been altered to an oxyd or sulphid of iron, or to other ores.

In many cases, the fossils are entirely dissolved out by percolating waters, leaving the rock full of cavities. This happens especially in sandstones, through which waters percolate easily, and not in clays, which latter preserve well the fossils committed to them; and hence sands, gravel, conglomerates and quartzose sandstones contain few organic remains.

3. KINDS OF ROCKS.

General subdivisions. — Rocks are conveniently divided into *fragmental* and *crystalline.*

1. *Fragmental.* — Rocks that are made up of pebbles, sand, or clay, the particles of sand, and even of clay, being strictly fragments broken from the rocks of the globe, either deposited as the sediment of moving waters, or formed and accumulated through other means, — as ordinary *conglomerates*, *sandstones*, *clay-rocks*, *tufas*, and nearly all *limestones.* The larger part of the rocks here included are made of sedimentary material, that is material deposited as sediments by marine or fresh waters; and are hence commonly called *sedimentary* rocks. They are *stratified* rocks, — that is, consist of layers spread out one over another. Many of them are *fossiliferous* rocks, or contain fossils.

2. *Crystalline.* — Rocks that have a crystalline instead of a fragmental character. The grains, when large enough to be visible, are

crystalline grains, and not water-worn particles or fragments of other rocks. Examples: granite, gneiss, mica schist, basalt.

The crystalline rocks may have been crystallized —

a. From fusion, like lava or basalt, when they are called *igneous rocks.* Igneous rocks are often called *eruptive* rocks, a term signifying that they have been ejected from below, through fissures intersecting other rocks.

b. From solution; as with the limestone called *travertine.*

c. Through long-continued heat, usually *without complete fusion.* By this last method, sedimentary beds, that is, those made originally from mud, clay, etc., have been altered into granite, gneiss, or mica schist, and compact limestone into statuary marble. Since, in such cases, a bed originally sedimentary has been *metamorphosed* into a crystalline one, rocks of this altered kind are called *metamorphic rocks.*

Distinctions of Rocks. — A few rocks consist of a single mineral alone: as, for example, *limestone*, which may be either the species calcite or dolomite; *quartzyte* (along with much sandstone), which is quartz; and *felsyte*, which is orthoclase. But even these simple kinds are seldom free from other ingredients, and often contain visibly other minerals. Nearly all kinds of rocks are combinations of two or more minerals. They are not definite compounds, but indefinite mixtures, and hardly less indefinite than the mud of a mud-flat. The limits between kinds of rocks are consequently ill-defined. Granite graduates insensibly into gneiss, and gneiss as insensibly into mica schist and quartzyte; and so it is with many other kinds. This fact is a chief source of the difficulty in studying and defining rocks, and especially the crystalline kinds.

In the study of any rock, the following are points to be determined: —

1. *Whether Fragmental or Crystalline in Texture.* — This is easily ascertained when the grains are coarse, those of fragmental rocks having their edges rounded, and those of crystalline rocks having them angular on a surface of fracture. But if fine-grained, it is best first to examine the rock over a large area, and see whether it graduates into coarser kinds that are obviously fragmental, or that contain a pebble here and there, or that contain fossils; or whether it is not so related to other fragmental or sedimentary beds in position that the doubt is thus removed; or whether a coarser kind is not crystalline-granular and hence a crystalline rock; or whether its connection with eruptive rocks in the region is not such as to settle the question. The examination of thin, transparent slices by the microscope will usually give definite information when other methods fail.

2. *The Nature of the Constituent Minerals.* — Rocks being mixtures of different minerals, it is of the highest importance to ascertain the species of minerals present, and especially with crystalline rocks.

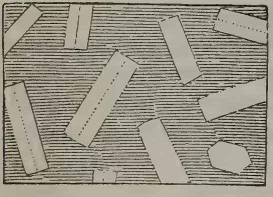
The rock may be limestone; if so, the test with acids given on page 55 will decide it. If not limestone, and the rock is coarse-granular, the several kinds of grains must be particularly studied, and their mineral nature ascertained, the pocket-lens being employed in the examinations, and such other helps as may be necessary. If fine-grained, and no transitions to coarser kinds occur in the region (which can afford obvious evidence as to the nature of the constituent minerals), it is generally necessary to examine thin, transparent slices by the microscope, and further to investigate the composition of the rock by chemical analysis.

The kind of rock being ascertained, the structure and texture of the rock-mass require study.

3. *The Structure of the Rock-mass.* — The constituent minerals may be promiscuously mingled as in granite; or they may be arranged partially in planes, giving it a banded or stratified appearance in a transverse fracture, as in gneiss and mica schist. In the latter case, the rock will break in the direction of the stratification, having what is called a schistose structure. The rock may be thick-bedded, or thin-bedded, even-bedded, or irregularly bedded. On page 79, and beyond, other kinds of structure, that may be looked for, are described.

4. *The Texture of the Rock.* — Some of the points to be noted as regards texture are (1) whether the rock is coarse-granular or fine-granular, or whether aphanitic (that is, having no grains visible to the naked eye, as in flint); (2) whether it is even-grained and homogeneous, or whether, in the case of crystalline rocks, one of the minerals is distributed in distinct crystals through the mass of the rock; whether, in such a case, the mass of the rock, called the *base*, is coarse-grained or not. When crystals of feldspar are scattered through the mass, as illustrated in the annexed figure (the white spots in which represent the feldspar crystals), the rock is said to be *porphyritic*, the porphyry of the ancients being a rock of this kind. The whitish spots are often rectangular, or nearly so, and are sometimes twin crystals. The feldspar crystals may be orthoclase, or a triclinic feldspar; and the base may be orthoclase, or true granite or gneiss, or other kind of rock-material, and either coarse-grained or aphanitic. The term porphyritic is sometimes applied also where pyroxene or hornblende is in distinct crystals in the rock-mass; but in this case, the rock should be described as porphyritic with pyroxene, or with hornblende.

Fig. 58.



Again, by the examination of thin slices of crystalline rock with the microscope, it may be ascertained whether the mass of the crystalline rock consists throughout of distinct grains crystalline in nature, or whether portions among the stony grains are of the nature of glass. Glass is a result of comparatively rapid cooling, too rapid for the crystallization of the whole of the mass; and in the glassy portions the material of the rock is said to be *unindividualized*, the component minerals of glass not being distinguishable.

Again, igneous rocks sometimes exhibit under the microscope a *fluidal* texture; that is, the material, when examined in sections, shows wavy lines or bands, which are evidence of a former fluid state, and of movement or flowing when in that state. Again, the crystals in the mass are sometimes found to be broken, as an effect of motion in the fluid mass after it was partly consolidated.

5. *The Specific Gravity of the Rock.*—This quality will vary in the same rock with the proportions of the constituents. If a rock consist chiefly of quartz, or of feldspar, the specific gravity will be between 2·4 and 2·75; but if it consist of either of these minerals along with the iron-bearing mineral hornblende, or augite, or epidote, the specific gravity may vary from 2·75 to 3·4, according to the proportions.

6. *Hardness, Firmness, Toughness, Durability.*— These are among the qualities referred to in describing rocks. But to a large extent the characters belong to some varieties of certain kinds of rocks, and not to any rocks in all their varieties. Quartz makes the hardest of rocks, and talc and gypsum the softest. At the same time many rocks consisting of quartz have little firmness or none. Firmness depends largely on degree of consolidation and closeness of texture. Some quartz rocks are very *friable* (rubbing to pieces easily in the fingers), and some beds of the same material are too soft to be called even sandstone. Granular limestone may vary in like manner, the rock of some beds being firm, and of others not far distant, fragile, if not friable.

Tough rocks are not made of minerals that have a vitreous or glassy lustre, with great hardness, for in such there is too much elasticity for toughness; but of those that yield somewhat under the hammer and are sub-vitreous or almost earthy in lustre. Hornblende makes the toughest of rocks, and to this the word *horn* in the name alludes; and it is especially effective when its crystallizations in the rock are oblong and interlace with the other grains present. Next to hornblende is serpentine, a mineral not harder than limestone.

Durability is due largely, other things being equal, to a fineness of grain and close compactness of texture sufficient to resist the effects over the surface of changes of temperature, and exclude moisture,

water and air being the chief means through which decomposition is carried forward. The best slate, when free from pyrite, is exceeded by no other rock in durability. Compact pure limestone is next to it in this respect; but this yields superficially to the dissolving powers of atmospheric waters. Want of durability may come (1) from openness of texture; (2) from the composition of the constituent minerals; and (3) largely from the composition of accessory minerals, like pyrite. See p. 687.

7. *A Study of the Accessory Minerals, or those not Essential Constituents of the Rock.* — All accessory minerals have prominent interest, and none more so than those revealed by the microscope. Some of the microscopic minerals occur inside of other crystals, and are hence called *inclusions*. Among the inclusions there are sometimes globules of liquid carbonic acid inside of crystals of quartz, topaz, and certain other hard and firm minerals; crystals of apatite or calcium phosphate, a mineral occurring microscopically in nearly all crystalline rocks; also cubes of common salt, and other crystallizations, part original to the rock, and part a result of changes that have taken place within it.

The following are some terms not explained above: —

Quartzose. Consisting of quartz; containing much quartz.

Calcareous. Consisting of limestone (calcite); containing much calcite.

Ferruginous. Containing much iron oxide.

Argillaceous (from *argilla, clay*). Made of more or less hardened clay or fine mud; containing clayey material.

Granitoid. Like granite in crystalline-granular condition.

Granitic. Made of granite, or of comminuted granite.

Amygdaloidal (from *amygdalum, an almond*). Having numerous spheroidal or almond-shaped cavities filled with minerals foreign to the rock, such as quartz, calcite, and the zeolites. Trap, or doleryte, and related basic eruptive rocks, are often *amygdaloidal*.

Scoriaceous. Slag-like, very open cellular, or inflated, like the scoria of a volcano or slag of a furnace.

Pyritiferous. Containing pyrite.

Cryptocrystalline. Having no grains visible in the texture. Same as *aphanitic*. The term *microscopic* is used for the same; and *macroscopic* for coarse-granular, or when the grains are large enough for a more or less perfect study of the rock without the use of the microscope. A rock may be studied *microscopically*, or *macroscopically*.

Acidic. Basic. Crystalline rocks contain usually — and the igneous, almost always — a feldspar as one of the ingredients. In a feldspar, the *silica* is the *acidic* constituent; and those feldspars which contain the larger percentage of silica — exceeding 60 per cent. — like *orthoclase*,

albite and *oligoclase*, are called *acidic* feldspars; and the others, especially *labradorite* and *anorthite*, in which the feldspar is less than 55 per cent., *basic* feldspars. So also crystalline rocks, whether metamorphic or eruptive, are called *acidic* rocks when one of the chief constituents is an acidic feldspar; and *basic*, when it is a basic feldspar.

Use of the Microscope in the Study of Rocks. — The study of thin, transparent slices of rocks by the microscope is of interest whether the crystalline rock be coarse or fine in texture; but it is particularly important when of the latter kind. There is no rock so opaque that it cannot be made transparent, or at least translucent, in thin slices. Such slices are examined by means of a polariscope-microscope. The more important points ascertained by this means, as regards the mineral constitution of the rock, are the following: —

1. The presence or not of quartz; of a feldspar; of a chlorite.
2. The distinction of a triclinic feldspar from orthoclase, the former showing in sections, cut in any direction excepting one, several parallel spectrum bands, due to multiple twinning in the crystal, while orthoclase shows no bands of the kind, or at the most but two.
3. The presence or not of hornblende; this mineral having often cleavage lines meeting at angles of 124°, and being *dichroic*.
4. The presence or not of pyroxene; this mineral often showing cleavage lines meeting at angles of 87° (nearly a right angle), and being *not* dichroic, and usually distinguishable in this way from hornblende.
5. The presence or not of mica, its cleavage lines meeting at angles of 60° and 120°.
6. The presence or not of chrysolite; of magnetite, its form being often octahedral; of points or portions having the nature of glass, and therefore not polarizing light; of fluidal lines; of globules of liquid carbonic acid, and of various other inclusions.

For a particular account of the distinguishing characteristics of minerals brought out by means of the microscope, reference must be made to treatises on the subject.

The kinds of rocks are described under the heads of —

1. Fragmental Rocks, exclusive of Limestones.
2. Limestones, or Calcareous Rocks.
3. Metamorphic Rocks, exclusive of Limestones.
4. Eruptive Rocks.

In the names of rocks, the termination *ite* is here changed to *yte*, as done in the author's "System of Mineralogy" (1868), in order to distinguish them from the names of minerals. Granite is excepted. The names of the more common kinds of rocks are printed in a **bolder** letter.

1. Fragmental Rocks, exclusive of Limestones.

1. **Conglomerate.** — A rock made up of pebbles or fragments of rocks of any kind. (*a*) If the pebbles are rounded, it is called *pudding-stone*; (*b*) if angular, *breccia*.

Conglomerates are named, according to their constituents, *siliceous* or *quartzose*, *granitic*, *calcareous*, *porphyritic*, *pumiceous*, etc.

2. **Grit, Grit-rock** — A hard, gritty rock, consisting of coarse sand, or sand and small pebbles, called also *millstone grit*, because used sometimes for millstones.

3. **Sandstone.** — A rock made from sand. There are *siliceous*, *granitic*, and *micaceous* sandstones, according to the character of the material. There are also *compact*, *friable*,

argillaceous, *gritty*, *ferruginous*, *concretionary*, *laminated*, *thick-bedded*, *thin-bedded*, *massive*, *shaly*, *flexible*, and other kinds. Grindstones are made of an even-grained, rather friable sandstone. Hard, siliceous sandstones, grit, and conglomerate, in regions of metamorphic rocks, are called *quartzyte* (p. 70).

4. **Sand-rock.** — A rock made of sand of any kind, especially if not siliceous or granitic. A *calcareous sand-rock* is one made of calcareous sand, as pulverized corals or shells.

5. **Shale.** — A soft, fragile, argillaceous rock, having an uneven, slaty structure. Shales are gray to black in color, and sometimes dull greenish, purplish, reddish.

VARIETIES. — a. *Bituminous shale ;* impregnated with petroleum, or with coaly material yielding mineral oil or related bituminous matters when heated; called also *Carbonaceous shale* (*Brandschiefer* in German). b. *Alum shale ;* impregnated with alum or pyrites, usually a crumbling rock. The alum proceeds from the alteration of pyrite or the allied pyrrhotite (p. 59).

6. **Argillyte,** *or Clay-slate* (*Phyllyte*). — An argillaceous slaty rock, like shale, but differing in breaking usually into thin and even slates or slabs. Roofing and writing slates are examples. It is sometimes thick-laminated. Moreover, unlike shale, it occurs in regions of metamorphic rocks, and often graduates into hydromica and mica slates.

7. **Tufa.** — Tufa is a rock, not very hard, made from comminuted volcanic or other igneous rock, more or less altered. Usually of a yellowish-brown, gray, or brown color; sometimes red. The tufa made from those igneous rocks that contain iron-bearing minerals, such as doleryte (trap), basalt, and the heavier lavas, is usually yellowish-brown or brown in color (sometimes red), and often consists in part of palagonite, a result of the alteration of the materials by means of heated water or vapor; and that made from the feldspathic igneous rocks, trachyte, pumice, and the like, are of an ash-gray color, or of other light shades. *Pozzuolana* is a light-colored tufa, found in Italy, near Rome, and elsewhere, and used for making hydraulic cement ; *Wacke*, earthy, brownish, resembling an earthy trap or doleryte, usually made up of trappean or dolerytic material compacted into a rock that is rather soft.

8. **Sand. Gravel.** — *Sand* is comminuted rock-material; but common sand is mainly comminuted quartz, or quartz and feldspar, while *gravel* is the same mixed with pebbles or stones. Sand often contains scales of mica, grains of magnetite and garnet. *Volcanic sand*, or *peperino*, is sand of volcanic origin, either the "*cinders*" or "*ashes*" (comminuted lava) formed by the process of ejection, or lava rocks otherwise comminuted.

9. **Clay.** — Soft, impalpable, more or less plastic material, chiefly aluminous in composition, white, gray, yellow, red to brown and black in color. See p. 58.

VARIETIES. — a. *Kaolin ;* purest unctuous clay. b. *Potter's clay ;* plastic, free from iron; mostly unctuous; usually containing some free silica. c. *Ferruginous, Brick-clay ;* containing iron in the state of oxide or carbonate, and consequently burning red, as in making red brick. d. *Containing iron in the state of a silicate*, and then failing to turn red on being burnt, as the clay of which the Milwaukee brick are made. e. *Alkaline* and *Vitrifiable ;* containing 2·5 to 5 per cent. of potash or potash and soda, owing to the presence of undecomposed feldspar, and then not refractory enough for pottery or fire-brick. f. *Marly ;* containing some carbonate of calcium. g. *Black, Ampelite ;* from the presence of lignitic or coaly material. h. *Alum bearing ;* containing aluminous sulphates, owing to the decomposition of iron sulphides present.

10. **Alluvium. Silt. Till.** — *Alluvium* is the earthy deposit made by running streams or lakes, especially during times of flood. It constitutes the flats adjoining, and is usually in thin layers, varying in fineness or coarseness, being the result of successive depositions. *Silt* is the same material deposited in bays or harbors, where it forms the muddy bottoms and shores. *Lœss* is an earthy deposit, coarse or fine, following the courses of valleys, like alluvium, but without division into thin layers.

Till is the unstratified sand, gravel, and stones, derived from glaciers.

Detritus (from the Latin for *worn*) is a general term applied to earth, sand, alluvium, silt, gravel, because the material is derived to a great extent from the *wear* of rocks

through decomposing agencies, mutual attrition in running water, and other methods (pp. 648, 688, 758).

Soil is earthy material, mixed with the results of vegetable and animal decomposition, whence it gets its dark color and also a chief part of its fertility.

11. **Tripolyte** (Infusorial Earth). — Resembles clay or chalk, but is a little harsh between the fingers, and scratches glass when rubbed on it. Consists chiefly of siliceous shells of Diatoms (p. 59). Forms thick deposits, and is often found in old swamps beneath the peat. Used as a polishing powder; also mixed with nitro-glycerine to make dynamite. Occurs sometimes *slaty*, as at Bilin, Prussia; and also *hard*, from consolidation through infiltrating waters. Consists of silica in the opal or soluble state.

2. Limestones, or Calcareous Rocks.

1. Not Crystalline.

1. **Massive Limestone.** — Compact uncrystalline limestone of dull gray, bluish-gray, brownish and black colors; in texture, varying from earthy to compact semi-crystalline. It consists essentially of calcite or *carbonate of calcium* (p. 55), but is often impure with clay or sand.

Most limestones have been made out of comminuted shells, corals, and other like material; and when of dark colors or black, it is usually owing to some carbonaceous matters present derived from the decomposition of the plants or animals of the waters in which they were formed. When burnt, limestone (CaO_3C) becomes *quicklime* (CaO), through loss of carbonic acid (CO_2); and, at the same time, all carbonaceous materials are burnt out, and the color, when it is owing solely to these, becomes white.

2. **Magnesian Limestone. Dolomyte** (p. 55). — Consists of carbonate of calcium and magnesium, but not distinguishable in color or texture from ordinary limestone. The amount of magnesian carbonate present varies from a few per cent. to that in true dolomite. Much of the common limestone of the United States is magnesian.

In some limestones the fossils are magnesian, while the rock is common limestone. Thus, an *Orthoceras* in the Trenton limestone of Bytown, Canada (which is not magnesian), afforded T. S. Hunt, Carbonate of calcium 56·00, carbonate of magnesium 37·80, carbonate of iron 5·95 = 99·75. The pale-yellow veins in the Italian black marble, called "Egyptian marble," are dolomite, according to Hunt.

3. **Hydraulic Limestone.** — A limestone containing some clay, and affording a quicklime the cement from which will "set" under water. An analysis of a kind from Rondout, N. Y., afforded Carbonic acid 34·20, lime 25·50, magnesia 12·35, silica 15·37, alumina 9·13, sesquioxyd of iron 2·25. In making ordinary mortar, quartz sand is mixed with pure quicklime and water, and the chemical combination is mainly that between the water and lime, together with an absorption subsequently of carbonic acid. With "hydraulic cement," silica and alumina (that of the clay) are disseminated through the lime, and hence these ingredients enter into chemical union with the lime and water, and make a much firmer cement, and one which "sets" under water.

4. **Oölyte.** — Limestone, either magnesian or not, consisting of minute concretionary spherules, and looking like the petrified roe of fish: the name is from the Greek ὠόν, egg.

5. **Chalk.** — A white, earthy limestone, easily leaving a trace on a board. Composition, the same as that of ordinary limestone.

6. **Marl.** — A clay containing a large proportion of carbonate of lime, — sometimes 40 to 50 per cent. If the marl consists largely of shells or fragments of shells, it is called *shell-marl*. Marl is used as a fertilizer; and other beds of clay or sand that can be so used are often in a popular way called *marl*. The "Green sand" of New Jersey (p. 455) is of this kind.

7. **Shell Limestone, Coral Limestone.** — A rock made out of shells or corals.

8. **Travertine.** — A massive limestone, formed by deposition from calcareous springs or streams. The rock abounds on the river Anio, near Tivoli, and St. Peter's, at Rome, is constructed of it. The name is a corruption of *Tiburtine*. It occurs in the Yellowstone Park, along Gardiner's River.

9. **Stalagmite, Stalactite.** — Depositions from waters trickling through the roofs of limestone caverns form calcareous cones and cylinders pendent from the roofs, which are called *stalactites*, and incrustations on the floors, which are called *stalagmite.* The waters, filtering down from the overlying soil, contain a little carbonic acid, and are thus enabled to dissolve the limestone, which is deposited again on evaporation. The layers of successive deposition are usually distinct, giving the material a banded appearance.

2. Crystalline Limestone.

1. **Granular Limestone** (Statuary Marble). — Limestone having a crystalline granular texture, white to gray color, often clouded with other colors from impurities. It is a *metamorphic* rock; it was originally common limestone; it became crystalline under the action of more or less heat; in the process, all the fossils present were obliterated, except in some cases of partial metamorphism. Its impurities are often *mica* or *talc, tremolite, white* or *gray pyroxene* or *scapolite ;* sometimes *serpentine,* through combination with which it passes into ophiolyte (p. 75); occasionally *chondrodite, apatite, corundum.*

Varieties. — a. *Statuary Marble;* pure white and fine grained. b. *Ornamental* and *Architectural Marble;* coarse or fine, white, and mottled of various colors, and, when good, free not only from iron in the form of pyrite, but also from iron or manganese in the state of carbonate with the calcium, and also from all accessory minerals, even those not liable to alteration, and especially those of greater hardness than the marble, which would interfere with the polishing. c. *Verd-antique,* or *ophiolyte.* d. *Micaceous.* e. *Tremolitic;* contains bladed crystallizations of the white variety of hornblende called tremolite. f. *Graphitic;* contains graphite in iron-gray scales disseminated through it. g. *Chloritic;* contains disseminated scales of chlorite. h. *Chondroditic;* contains disseminated chondrodite in large or small yellow to brown grains.

2. **Dolomyte.** — Not distinguishable by the eye from granular limestone.

3. Metamorphic Rocks, not Calcareous.

Metamorphic rocks are made from the sedimentary rocks above enumerated by some crystallizing process, and vary exceedingly in the perfection of the crystallization they have undergone. Granite stands at one end of the series, and bard sandstones called quartzyte, hard slates like roofing-slate, and partially crystallized limestones, at the other; so that a distinct line between them and the sedimentary beds cannot always be drawn. The rocks of most veins are similar in nature. Some chemically deposited siliceous formations are included.

The common ingredients are *quartz, feldspar* of different kinds, *mica,* of the species *muscovite* and *biotite,* and sometimes also a *hydrous mica, hornblende, pyroxene, talc, epidote, chlorite, serpentine;* to which *garnet, andalusite, staurolite, tourmaline, topaz,* and *graphite* may be added as characterizing prominent varieties.

The rocks are described beyond in the following order: —

1. Quartzose rocks, consisting chiefly of quartz.
2. Mica-Orthoclase Series, or the Granite group.
3. The Hornblende Series and Pyroxene Series, including Syenyte, Dioryte, etc.
4. Garnet, Epidote, and Chrysolite rocks.
5. Hydrous Magnesian and Aluminous rocks, including kinds consisting largely of talc, chlorite, serpentine, pyrophyllite, etc.
6. Iron-ore rocks.

1. Quartzose Rocks.

1. **Quartzyte, Granular Quartz.** — A siliceous sandstone, usually very firm, occurring in regions of metamorphic rocks. It does not differ essentially from the harder siliceous sandstones of other regions. Conglomerate beds are sometimes included.

Varieties. — a. *Massive.* b. *Schistose.* c. *Calcareous.* d. *Micaceous* ("Greisen") or *Hydromicaceous.* e. *Feldspathic,* and sometimes *Porphyritic.* f. *Gneissoid,* it occasionally graduating into gneiss. g. *Tourmalinic,* containing tourmaline.

2. **Itacolumyte.** — Schistose, consisting of quartz grains with some hydrous mica. On account of the mica, it is sometimes flexible, and is called *flexible sandstone.*

3. SILICEOUS SLATE. — Schistose, flinty, not distinctly granular in texture. Sometimes passes into mica slate or schist.

4. CHERT. — An impure flint or hornstone occurring in beds or nodules in some stratified rocks. It often resembles *felsyte*, but is infusible. Colors various. Sometimes oölitic. Kinds containing iron oxide graduate into jasper and clay-ironstone.

5. JASPER ROCK. — A flinty siliceous rock, of dull red, yellow, or green color, or some other dark shade, breaking with a smooth surface like flint. It consists of quartz, with more or less clay and oxyd of iron. The red contains the oxyd of iron in an anhydrous state, the yellow in a hydrous; on heating the latter it turns red.

6. BUHRSTONE. — A cellular siliceous rock, flinty in texture. It is used for millstones. Found mostly in connection with Tertiary rocks, and formed apparently from the action of siliceous solutions on preëxisting fossiliferous beds.

7. FIORYTE (*Siliceous Sinter*, *Pearl Sinter*, *Geyserite*). — Opal-silica, in compact, porous, or concretionary forms, often pearly in lustre; made by deposition from hot siliceous waters, as about geysers (*geyserite*), or through the decomposition of siliceous minerals, especially about the fumaroles of volcanic regions. Geyserite is abundant in Yellowstone Park, and about the Iceland geysers; after long exposure it *crumbles down* and becomes changed to ordinary silica or quartz.

2. THE MICA-ORTHOCLASE SERIES, OR GRANITE GROUP.

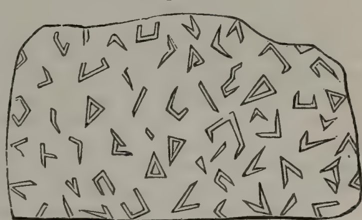
In this series the chief constituents are quartz, orthoclase (and microcline), or potash-feldspar, and the two potash-micas, muscovite and biotite. The presence of much potash is a marked characteristic, each of the micas containing 10 per cent. or more of it, and the feldspar usually over 12. The two micas often occur together; the black, or biotite, is most common. The mica is sometimes a hydrous species — margarodite or damourite. The series graduates into feldspathic rocks, like granulyte, containing little or no mica, and into rocks containing little besides mica. Specific gravity between 2·4 and 2·75. Accessory minerals: *albite* and *oligoclase*, *hornblende*, *garnet*, etc. Occasionally, especially in vein granite, the orthoclase is nearly or wholly replaced by one of the triclinic feldspars. Sometimes the iron mica, *lepidomelane*, replaces biotite.

1. **Granite.** — Consists of quartz, feldspar, and mica, and has no appearance of layers in the arrangement of the mica or other ingredients. The *quartz* is usually grayish or smoky white, glassy, and *without any appearance of cleavage.* The *feldspar* is commonly whitish or flesh-colored, less glassy than the quartz, and cleaves in two directions. The mica is in very cleavable scales.

Metamorphic granite is common in Connecticut and other parts of New England, where it may be often seen graduating into gneiss, or in alternating layers with it.

VARIETIES. — There are, A, Muscovite-granites; B, Biotite-granites; C, Muscovite-and-biotite granites, the last much the most common. The most of the following varieties occur under each except the hornblendic, which is usually a Biotite or Muscovite-and-biotite granite. There is also, D, Hydromica-granite. a. *Common* or *ordinary granite.* The color is grayish or flesh-colored, according as the feldspar is white or reddish, and dark gray when much black mica is present. Granite varies in texture from fine and even to coarse; and sometimes the mica, feldspar, and quartz — especially the two former — are in large crystalline masses. An average granite (mean of 11 analyses of Leinster granite, by Haughton) consists of Silica 72·07, alumina 14·81, protoxyd and sesquioxyd of iron 2·52, lime 1·63, magnesia 0·33, potash 5·11, soda 2·79, water 1·09 = 100·35. b. *Porphyritic granite;* has the orthoclase in defined crystals, and

Fig. 59.



may be (α) small-porphyritic, or (β) large-porphyritic, and have the base (γ) coarse granular, or (δ) fine, and even subaphanitic. c. *Albitic granite;* contains some albite, which is usually white; rarely, albite is the predominating feldspar, and then the rock is *albite-granite.* d. *Oligoclase granite* (*Miarolite*); contains oligoclase. e. *Microcline granite;* contains the potash triclinic feldspar, microcline. f. *Hornblendic granite;* contains black or greenish-black hornblende, along with the other constituents of granite. g. *Black micaceous granite;* consists largely of mica, with defined crystals of feldspar (porphyritic), and but little quartz. h. *Globuliferous granite;* contains concretions which consist of mica, or of feldspar and mica. i. *Gneissoid granite;* a granite in which there are traces of stratification; graduates into gneiss. j. *Pegmatyte*, or *Graphic granite;* consists mainly of orthoclase and quartz, with but little whitish mica; but the quartz is distributed through the feldspar in forms looking like Oriental characters (Fig. 59).

2. **Granulyte** (*Leptynyte*). — Like granite, but containing no mica, or only traces.

VARIETIES. — a. *Common* granulyte; white and usually fine granular. b. *Flesh-colored;* usually coarsely crystalline, granular, and flesh-colored. c. *Garnetiferous.* d. *Hornblendic;* containing a little hornblende — a variety that graduates into syenyte. e. *Magnetitic;* containing disseminated grains of magnetite.

3. **Gneiss.** — Like granite, but with the mica and other ingredients more or less distinctly in layers, gneiss and granite being closely related rocks. Gneiss breaks most readily in the direction of the mica layers, and thus affords slabs, or is schistose in structure.

VARIETIES. — Most of them are similar to those under granite. a. *Porphyritic.* b. *Albitic.* c. *Oligoclase-bearing.* d. *Hornblendic.* e. *Micaceous.* f. *Globuliferous.* g. *Epidotic.* h. *Garnetiferous.* i. *Andalusitic*, or containing andalusite in disseminated crystals. j. *Cyanitic;* contains cyanite. k. *Graphitic;* contains graphite disseminated through it. l. *Quartzose;* the quartz largely in excess. m. *Quartzytic;* consists largely of quartz in grains, and intermediate between quartzyte and gneiss.

Some gneiss is very little schistose, being in thick, heavy beds, granite-like, while other kinds, especially those containing much mica, are thin-bedded, and very schistose; the latter graduate into mica schist.

4. **Mica Schist.** — Consists largely of mica, with usually much quartz, some feldspar, and, on account of the mica, divides easily into slabs, that is, is very schistose. Usually both of the potash micas, muscovite and biotite, are present, and the latter (black mica) is commonly much the most abundant. The colors vary from silvery to black, according to the mica present. Often crumbles easily, and roadsides are sometimes spangled with the mica scales.

VARIETIES. — a. *Gneissoid;* between mica schist and gneiss, and containing much feldspar, the two rocks shading into one another. b. *Hornblendic.* c. *Garnetiferous.* d. *Staurolitic.* e. *Cyanitic.* f. *Andalusitic.* g. *Fibrolitic;* containing fibrolite. h. *Tourmalinic.* i. *Calcareous*, limestone occurring in it in occasional beds or masses. j. *Graphitic*, or *Plumbaginous;* the graphite being either in scales or impregnating generally the schist. k. *Quartzose;* contains much quartz. l. *Quartzytic;* a quartzyte with more or less mica, rendering it schistose; m. *Specular*, or *Itabyrite;* containing much hematite or specular iron in bright metallic lamellæ or scales. n. *Mica slate;* or fine grained mica schist, the scales of mica scarcely visible without a lens, the rock being between a mica schist and argillyte. This variety of the rock is often *garnetiferous*, and sometimes *staurolitic* Sometimes through mica schist or slate small mica crystals are disseminated, set transversely to the bedding.

5. **Hydromica Schist or Slate.** — A thin schistose rock, consisting either chiefly of hydrous mica, or of this mica with more or less quartz; having the surface nearly smooth, and feeling greasy to the fingers; pearly to faintly glistening in lustre; whitish, grayish, pale greenish in color, and also of darker shades. This rock used to be called *talcose slate*, but, as first shown by Dr. C. Dewey, it contains no talc. It includes *parophite schist*, *damourite slate*, and *sericite slate* (*glanz-schiefer*, *sericit-schiefer*, and part of the *glimmer-schiefer* of the Germans).

VARIETIES. — a. *Ordinary;* more or less silvery in lustre. b. *Chloritic;* contains chlorite, or is mixed with chlorite slate, and has therefore spots of olive-green color;

graduates into chlorite slate. c. *Garnetiferous.* d. *Pyritiferous;* contains pyrite in disseminated grains or crystals. e. *Magnetitic;* contains disseminated magnetite. e. *Quartzytic;* consists largely of quartzyte, or is a quartzyte rendered schistose and partly pearly by the presence of a hydrous mica.

6. Argyllitic Hydromica Schist (*Hydromica Argillyte*). — Includes the Argillyte or clay-slate which has the composition nearly of a hydrous mica, like that of the White Mountain Notch, where much of it is Andalusitic.

7. Paragonite Schist or Slate. — Consists largely of the hydrous soda mica called paragonite; but in other characters resembles hydromica slate.

8. Miascyte. — Granitoid, and containing massive nephelite (elæolite) along with orthoclase, biotite, some quartz, and also sodalite.

9. **Felsyte** (*Euryte*, *Petrosilex*). — Compact orthoclase with often some quartz intimately mixed, flint-like in fracture. Opaque. Colors grayish-white to red and brownish-red. Sp. gr. = 2·6–2·7.

Varieties. — a. *Porphyritic Felsyte*, or *Porphyry;* containing the feldspar in small crystals distributed through the compact base; color red, and of other shades. b. *Conglomerate felsyte;* containing pebbles, as at Marblehead, Mass., and in the White Mountains. c. *Quartzose;* containing quartz in grains; often called *quartz-felsyte*, and *quartz-porphyry*. d. *Elvanyte;* essentially a quartzose felsyte, of gray, bluish-gray to brown and red colors, and often containing disseminated grains or crystals of quartz and feldspar. The feldspar is sometimes oligoclase. Some compact slate-rock has the same composition.

10. Porcelanyte, or *Porcelain-Jasper*, is a baked clay, having the fracture of flint and a gray to red color: it is somewhat fusible before the blowpipe, and thus differs from jasper. Formed by the baking of clay-beds, when they consist largely of feldspar. Such clay-beds are sometimes baked to a distance of thirty or forty rods from a trap dike, and over large surfaces by burning coal beds.

3. Hornblende Series. Pyroxene Series.

1. *Contain orthoclase and hornblende as prominent constituents; the hornblende often associated with biotite, and sometimes replaced by epidote.*

1. **Syenyte, Quartz-syenyte.** — A granitoid rock consisting of hornblende and orthoclase, with or without quartz. The quartziferous variety, or *quartz-syenyte*, is the original syenyte of Syene, Egypt. Like that, the rock is often flesh-colored; but whitish and grayish varieties are also common. Under the quartz-syenyte and quartzless syenyte there are the following

Varieties. — a. *Porphyritic.* b. *Albitic;* containing albite in addition to the constituents of true syenyte. c. *Oligoclase-bearing.* d. *Garnetiferous.* e. *Epidotic;* containing disseminated epidote.

2. **Syenyte-gneiss.** — Like gneiss in aspect and schistose structure; and also in constitution, except that hornblende replaces mica. Graduates into

3. **Hornblende-schist,** a schistose rock consisting chiefly of hornblende.

4. Unakyte. — A flesh-colored, granitoid rock consisting of orthoclase, quartz, and epidote. From the Unaka Mountains, N. Carolina, and E. Tennessee.

5. Zircon-syenyte. — A crystalline granular rock consisting of orthoclase, microcline, little hornblende, crystals of zircon, and some elæolite.

Foyayte and Ditroyte are other orthoclase rocks containing elæolite with some hornblende; but they are described as eruptive.

2. *Contain a triclinic feldspar and hornblende as prominent constituents.*

1. **Dioryte. Quartz-dioryte.** — The triclinic feldspar, one of the acidic (rich in silica) species, albite or oligoclase. Texture, granitoid to fine-grained or compact. Color often grayish-white to greenish-white, for the coarser kinds; olive-green to blackish-green for the finer. Very tough. Sp. gr. 2·7–3·0.

Varieties. — a. *Granitoid;* granite-like in texture. b. *Compact;* or fine-grained, with the feldspar grains scarcely distinguishable. c. *Porphyritic;* the feldspar in crystals in a compact base. d. *Slaty;* a dioryte slate, usually chloritic. e. *Quartzose*, or

quartz-dioryte; containing quartz in disseminated grains. The porphyritic varieties include dark red and brownish-red ancient porphyries, as well as dark green kinds, and may also be quartzose; they have been called *porphyrite.*

2. **Labradioryte** (*Labradorite Dioryte*). — The feldspar, one of the basic (poor in silica) species, labradorite or anorthite. Texture usually fine-grained, sometimes cryptocrystalline. Color light grayish-green to dark olive-green, blackish-green, or gray, and sometimes black. Very tough. Sp. gr. = 2·8–3·1. Often contains chlorite and also magnetite. Often has associated with it beds of serpentine or ophiolyte.

Varieties. — a. *Granular crystalline.* b. *Compact,* or fine grained, of dark green color; constituent minerals not distinct. c. *Porphyritic;* the feldspar in whitish or greenish-white crystals disseminated through a fine-grained base, making a greenish "porphyry." d. *Pyroxenic;* containing some disseminated pyroxene. e. *Magnetitic.*

3. *Contain a triclinic feldspar and pyroxene or hypersthene as the prominent constituents.*

1. Gabbro (*Gabbro,* in part, *Hyperite*).— A basic granitoid rock in part, consisting of cleavable labradorite with disseminated pyroxene, or a granular crystalline aggregate of the two minerals. The pyroxene often in a lamellar state, improperly called hypersthene. In place of labradorite, the feldspar is sometimes andesite, and sometimes anorthite. Color, dull flesh-red to brownish-red, also dark-gray to grayish-black. Tough. Sp. gr. 2·7–3·1, varying with the proportion of pyroxene, which is sometimes small. Contains also magnetite or titanic iron.

The name *gabbro* has been applied to this rock; also to a coarsely granular igneous rock, consisting chiefly of labradorite and foliated pyroxene, referred beyond to doleryte; to euphotide; and, by the Italians, to a diallage-bearing serpentine. Ferber, in his "Briefe" (1773), says (p. 98) *Gabbro,* of Florence is the same as the rock called "sächsischen Serpentin, in Deutschland," that is, the serpentine of Zöblitz.

Varieties. — a. *Granitoid;* the feldspar in distinct cleavable grains or masses. b. *Feldspathose;* the pyroxene feeble in amount. c. *Chrysolitic;* contains disseminated chrysolite in addition to the other ingredients. d. *Anorthitic,* or *Tractolite;* anorthite replacing the labradorite.

Another rock, also called *gabbro,* has the aspect of euphotide (page 75), into which it graduates; but the compact whitish or greenish base, instead of being saussurite, is true labradorite (its sp. gr. about 2·7). The other chief constituent is light green smaragdite, which is a lamellar variety of hornblende, but sometimes partly or wholly pyroxene. Occurs with the euphotide of the Alps.

2. Noryte (*Hypersthenyte*). — A rock resembling the preceding, consisting of cleavable labradorite with *true* foliated hypersthene.

4. *Consist mainly of hornblende or pyroxene.*

1. **Hornblende Schist.** — A schistose rock consisting mainly of greenish-black hornblende with usually some quartz or orthoclase.

Varieties. — a. *Quartzose;* consisting of hornblende and quartz. b. *Epidotic.* c. *Garnetiferous.* d. *Micaceous.* Graduates into

2. Amphibolyte or Hornblendyte. — A very tough, granular-crystalline rock, consisting of hornblende, and hardly schistose in structure. Color, greenish-black to black, often *Garnetiferous;* sometimes *Chrysolitic.* Graduates into

Aphanite, a cryptocrystalline hornblende rock of black color. Aphanite is in part a cryptocrystalline dioryte.

3. Actinolyte. — A tough, massive rock made chiefly of actinolite. Grayish green.

4. Pyroxenyte. (*Augite Rock*). — Coarse or fine granular pyroxene rock.

4. Garnet, Epidote, and Chrysolite Rocks.

1. Garnetyte, or Garnet Rock. — A yellowish-white to greenish-white, tough rock, consisting of an alumina-lime garnet. Sp. gr. 3·39–3·49. From St. Francis, Canada. The yellow whetstone of Vieil Salm, Belgium, has the composition of garnet.

2. Eclogyte. — Compact and tough. Consists of granular garnet and hornblende, with grass-green smaragdite. Sp. gr. 3·2–3·5. A related rock consists of reddish or brownish-yellow garnet, and black or greenish-black hornblende, with often some magnetite.

3. EPIDOSYTE. — Pale green to pistachio-green. Epidote mixed with quartz.

4. EUPHOTIDE (*Gabbro*, in part). — Whitish to greenish; compact and tough. Made up of compact saussurite, which is usually near labradorite in composition but has sp. gr. = 3 or above, and smaragdite, a light green, lamellar hornblende that is sometimes changed to pyroxene. Often contains serpentine. Occurs in the Alps, etc.

5. EULYSITE. — Fine-granular, consisting of chrysolite with a diallage-like mineral and garnet. Forms a bed in gneiss near Tunaberg, Sweden.

6. CHRYSOLITE-ROCK, or CHRYSOLYTE. — Yellowish to pale olive-green, granular; consisting almost wholly of chrysolite. Sp. gr. 3–3·1; H. 5·5–6. Abundant in Macon Co., N. Carolina; in part changed to serpentine. For *Dunyte*, which is supposed to be eruptive, and also *Lherzolyte*, *Picryte*, *Limburgyte*, see p. 79.

5. HYDROUS MAGNESIAN AND ALUMINOUS ROCKS.

Contain one or more of the hydrous magnesian minerals, chlorite, talc, serpentine; or the related hydrous aluminous mineral, pyrophyllite. The series commences in a granitoid or gneissoid species. The fine-grained kinds are more or less greasy to the touch; and some of them resemble the hydromica slates.

1. **Protogine.** A gneiss-like or granitoid rock consisting of orthoclase, quartz, and mica, with talc. Color grayish-white, greenish-white, and greenish-gray. *Porphyritic, micaceous*, and *oligoclase-bearing* varieties occur.

2. **Chlorite Schist** or **Slate**. — Schistose; color, dark green to grayish-green and greenish-black; but little, if any, greasy to the touch. Consists of chlorite, with usually some quartz and feldspar intimately blended, and often contains crystals (usually octahedrons) of magnetite, and sometimes chlorite in distinct scales or concretions.

VARIETIES. — a. *Ordinary*. b. *Hornblendic;* the hornblende in grains or needles. c. *Magnetitic*. d. *Tourmalinic*. e. *Garnetiferous*. f. *Pyroxenic*. g. *Staurolitic*. h. *Epidotic*. Graduates into

3. CHLORITE-ARGILLYTE. — An argillyte or clay-slate consisting largely of chlorite.

4. TALCOSE SLATE. — A slate or schist consisting chiefly of talc. Not common, except in local beds, most of the so-called "talcose slate" being hydromica slate (p. 72).

5. STEATYTE, SOAPSTONE (p. 55). — Consists of talc. Massive, more or less schistose; granular to aphanitic. Color, gray to grayish green and white. Feels very soapy. Easily cut with a knife.

VARIETIES. — a. *Coarse-granular*, and massive or somewhat schistose. b. *Fine-granular;* "French chalk." c. *Aphanitic*, or *Rensselærite;* of grayish-white, greenish brownish to black colors; from St. Lawrence Co., N. Y., and Grenville, Canada.

6. **Serpentine** (p. 55). — Aphanitic or hardly granular; of dark-green to greenish-black color, easily scratched with a knife, and often a little greasy to the feel, on a smooth surface. Although generally dark green, it is sometimes pale grayish and yellowish-green, and mottled.

7. OPHIOLYTE (Verd-Antique Marble). — A mixture of serpentine with limestone, dolomite, or magnesite, having a mottled green color. Often contains disseminated magnetite or chromite.

VARIETIES. — a. *Calcareous;* b. *Dolomitic;* c. *Magnesitic*. Either of these kinds may contain chromite or magnetite.

8. PYROPHYLLYTE and PYROPHYLLYTE SLATE. — Like the preceding in appearance and soapy feel, but having the composition of pyrophyllite (p. 58). The color is white and gray or greenish white. Occurs in North Carolina; one of the varieties from the Deep River region is used for slate pencils.

6. IRON-ORE ROCKS.

SPECULAR IRON-ORE (*Hematite*) and MAGNETIC IRON-ORE occur as rocks of considerable thickness among the metamorphic rocks, especially the hornblendic and chloritic kinds. There are schistose or laminated as well as massive varieties. Their alternation with chloritic and other schists and gneissoid rocks shows that they are metamorphic as well as the schists. They occur chiefly in Archæan regions; but the upper

Silurian limestone of Bernardston, Mass., and Devonian strata full of fossils at Moose River, in Nova Scotia, contain beds of magnetic iron ore, and at Nictaux there is in the Devonian a bed of hematite six feet thick. *Titanic iron* occurs in great beds of like extent in Canada, and is mixed with the magnetite of northern New York and western North Carolina. *Itabyrite* is a mica schist consisting largely of hematite.

Franklinite, an iron-zinc ore, is also one of the metamorphic rocks in northern New Jersey.

4. Igneous or Eruptive Rocks.

Igneous rocks are those which have been ejected in a melted state, either from volcanoes or through fissures in the earth's crust. Their most general characteristics are: (1) the presence of a feldspar as one of their constituents; (2) with most kinds, absence of free quartz; (3) occurring often as the filling of fissures (pp. 738, 740), as well as in overlying masses, or intercalated between layers of stratified rocks.

Igneous rocks are not always easily distinguished from metamorphic rocks, or those of the veins, and a few kinds of the two divisions are identical. In the metamorphic process, a stratified rock has sometimes been reduced to a pasty state, and in this condition has been forced into fissures, and so has taken the position, and, as it cooled, the crystalline texture and aspect of an igneous rock. Some granite is an example. Again, true igneous rocks have at times resulted from the fusion (or an equivalent softening) of preëxisting crystalline rocks (granite, syenyte, and the like), and so have derived a constitution more or less resembling that of the rock out of which they were made. Thus igneous rocks, although generally containing little or no quartz, may in some cases abound in grains of this mineral.

The same igneous rock often occurs in various conditions, dependent (A) on rate of cooling; and (B) on its remaining unaltered, or its being altered by water and other vapors received from sources in or among the earth's strata when the melted rock was on its way to the surface. It may thus vary —

A. From coarsely crystalline granular to aphanitic; from an even-grained rock to coarsely porphyritic, in which the feldspar is in distinct crystals; from the condition in which every grain, as seen in thin slices with the microscope, is a defined mineral, to that in which portions or points are in the state of glass or "unindividualized," from an even homogeneous texture to one in which there are fluidal lines, as explained on p. 65.

B. From the condition in which the minerals of the rock, feldspar, hornblende, and augite become pellucid when the rock is sliced thin, to that in which they are more or less clouded, and a green chlorite — a hydrous species — occupies the place of part of these minerals, and perhaps other results of alteration are manifest; also from the condition of perfect compactness to that of a cellular or amygdaloidal structure, amygdaloidal cavities being a result of vapors.

Hence criterions for distinguishing kinds of igneous rocks based on their being coarse-grained or aphanitic; not porphyritic or porphyritic; containing glassy grains in the mass, or being wholly "individualized;" showing fluidal lines or not; being unaltered and anhydrous, or, on the other hand, hydrous, chloritic, and amygdaloidal, are unsatisfactory.

Further, rocks, as objects in science, should be defined and named *according to their kinds*, — not according to the era of formation, — since the same things are the same whenever made. The distinction of diabase from doleryte, based on being pre-Tertiary or not, and others similar, has been proved to be bad lithologically as well as geologically.

Apatite in microscopic crystals, and magnetite or titanic iron in crystalline grains, are present in nearly all varieties of igneous rocks.

Eruptive rocks may be arranged in three series, though no strong lines can be drawn between them.

1. A *feldspathic* series, the species containing little or no hornblende or pyroxene, and hence but little iron, and of low specific gravity (2·4–2·7).

2. A *hornblende and augite* series, the species containing as prominent ingredients, besides a feldspar, hornblende or augite (iron-bearing minerals), with often magnetite or titaniferous iron, and hence of high specific gravity (2·7–3·5).

3. A *chrysolitic* series, the species containing chrysolite and other ingredients, with little or no feldspar.

1. Feldspathic Series.

1. **Granite.** — Similar to metamorphic granite (p. 71).

2. **Granulyte.** — Similar to metamorphic granulyte (p. 72).

3. **Felsyte.** — Similar to metamorphic felsyte (p. 73) in its aphanitic texture. Colors gray, brown, and red. Consists of orthoclase, with or without some quartz intimately blended; also, in other cases, in part of oligoclase.

Varieties. — A. *Orthoclase felsyte;* B. *Oligoclase-bearing felsyte;* and under each the following kinds: a. *White* or *gray*. b. *Red* or *brownish-red*. c. *Porphyritic;* with the base red or brown or of other shades. d. *Fine-granular*. e. *Cellular* or *amygdaloidal.*

Some felsyte has nearly the aspect of trachyte, with which it is identical in composition.

4. **Phon lyte** (Clinkstone). — Compact, of grayish-blue and other shades of color, more or less schistose or slaty in structure; tough, and usually clinking under the hammer like metal when struck, whence the name. Sp. gr. 2·4–2·7. Consists of glassy feldspar (orthoclase or oligoclase), with nephelite and some hornblende; G. Jenzsch gives, for the composition of the Bohemian phonolyte, — Sanidin (glassy orthoclase) 53·55, nephelite 31·76, hornblende 9·34, sphene 3·67, pyrite 0·04. Under treatment with acids, the nephelite is dissolved out. Nosean and hauyne occur in some phonolyte.

5. **Trachyte.** — Consists mainly of feldspar, which is partly in glassy crystals, either sanidin or oligoclase; and owing to the angular forms of the glassy feldspar and the porosity of the rock, the surface of fracture is rough, whence the name from the Greek, τραχύς, *rough.* Color ash-gray, greenish-gray, brownish-gray, but sometimes yellowish and reddish. Sp. gr. 2·5–2·7. Besides the feldspar, there are distributed somewhat sparingly through the mass, in many kinds, minute needles of hornblende, crystals of biotite mica, magnetite; sometimes nephelite, hauyne, tridymite. Apatite exists in the rock in microscopic forms, and there are also particles of the rock in a glassy state. Sometimes contains augite and has higher specific gravity.

Varieties. — The two principal divisions are: A. *Sanidin-trachyte,* in which the mass is chiefly sanidin; and B. *Oligoclase trachyte,* or *domyte,* in which it is partly oligoclase; but the two graduate into one another. Both occur *porphyritic* with tabular crystals of feldspar; and in the latter (as at Drachenfels) the tables are sanidin. Each may contain free quartz, becoming thereby *quartz-trachyte.* Each graduates also into *vesicular* or *scoriaceous trachyte.*

Trachyte and *quartz-trachyte* graduate into felsyte like volcanic rocks of like constitution, porphyritic, or not so. The latter sometimes graduates into rocks of semi-glassy nature called

6. Pearlstone, when somewhat pearly in lustre; Pitchstone, when having a pitch-like lustre; and these into the glassy volcanic material called *Obsidian.* These glassy rocks often contain spherules which are concretions consisting of feldspar with some quartz. *Pumice* is a light, porous, feldspathic scoria, with the pores capillary and parallel. Ordinary obsidian, that consists chiefly of feldspar, and is hence nearly free from iron, belongs here, the rest of it belonging with the augitic igneous rocks. Obsidian, pitchstone, pearlstone, and some other kinds of igneous rocks have been classed together and called *rhyolyte,* from the Greek ῥύω, *I flow,* because showing in their microscopic structure, if not also externally, that they have flowed as lavas. But this fluidal feature belongs to rocks of very different kinds, and is only of varietal value.

7. Leucityte. — A grayish rock consisting chiefly of leucite in a felsitic state, with disseminated leucite crystals. Occurs at Point of Rocks, Wyoming Territory, according to King and Zirkel.

2. Hornblende and Augite Series.

In the rocks of this series magnetite or titanic iron is almost always present, as well as apatite. Some augitic kinds contain native iron in grains and rarely in masses.

The sections are: (1) *The rocks having hornblende as a prominent constituent*, including syenyte, dioryte (with propylyte), andesyte; (2) *The rocks containing augite, with little or no hornblende*, including augite-andesyte, doleryte (with diabase), amphigenyte, nephelinyte, and some obsidian. The rocks of the second division, excepting the first mentioned, are *basic* rocks. The term *trap* was early applied in Sweden (from *trappa*, *step*) to the compact columnar doleryte or basalt. The augitic kinds are often amygdaloidal.

1. **Syenyte** and **Quartz-syenyte.** — See p. 73 for description.

2. **Dioryte** and **Quartz-dioryte.** — See p. 73. *Propylyte* and *quartz-propylyte* have the same constitution. The former is the prevailing igneous rock of the Washoe district (vicinity of the Comstock lode), in Nevada; it is a grayish-green rock, yielding, on analysis, 64 to 66 per cent. of silica, and containing, along with oligoclase, hornblende, disseminated in minute points, and rarely also biotite.

3. Andesyte and Quartz-andesyte. — Andesyte is similar to the last, but affords about 60 per cent. of silica. The original andesyte from the Andes contains the feldspar andesite along with hornblende, which gives silica 57 to 60 per cent., while oligoclase gives 61 to 64 per cent. As in the preceding, the hornblende is sometimes changed to chlorite.

Quartz-Andesyte, or *Dacyte*, is a quartz-bearing variety. Both kinds occur in the Washoe district.

4. Variolyte (of Durance). — Consists of concretions of oligoclase and green hornblende, with some grains of pyroxene, in a fine-grained partly amorphous base, which is made up of labradorite, green and black hornblende, and an ill-defined material serpentine-like in aspect, and partly fluidal in texture. The nodular contains 57 per cent. of silica, and the base 45 per cent.

5. Corsite. — A granitoid rock, consisting chiefly of anorthite and hornblende, with some quartz, and biotite from Corsica.

6. Augite-Andesyte. — Contains the same triclinic feldspar as andesyte, but augite is present in place of hornblende. Amount of silica obtained in analysis about 55 to 58 per cent. Texture crystalline-granular to aphanitic; colors dark-gray to greenish-black and brownish-black. Sp. gr. 2·65–2·90.

Varieties. — There are two series: A. *Ordinary*, that is, without chrysolite, or only in traces. B. *Chrysolitic*, chrysolite being in disseminated grains or crystals. Under each there are other varieties: a. *anhydrous;* b. *hydrous*, or *chloritic*, and feeble in lustre; and c. *amygdaloidal*, as well as *chloritic*. Again, each of these varieties may be *porphyritic*. To the hydrous rock, and especially the chrysolitic, the term *melaphyre* is sometimes applied.

Ophite has nearly the composition of augite-andesyte, but contains diallage, and more resembles euphotide. Sometimes it contains serpentine disseminated among the other minerals. Some authors have made it metamorphic. There is also an oligoclase-ophite, containing much quartz.

7. **Doleryte** (Basalt). — Chief constituents, labradorite, or anorthite, and augite, with magnetite. Amount of silica yielded on analysis usually 47 to 52 per cent. Texture crystalline-granular to aphanitic. Colors dark grayish to greenish-black and brownish-black. Sp. gr. 2·75–3·1.

Varieties. — There are two series: A. *Ordinary;* B. *Chrysolitic;* and for the latter the name *peridotyte* has been used. Each occurs: a. *anhydrous;* b. *hydrous*, or *chloritic*, of feeble lustre; c. *amygdaloidal*, as well as chloritic; d. *vesicular*, or *scoriaceous*, as in doleritic lavas. Again, each of these varieties may be *porphyritic*. A coarse-granular kind, having the pyroxene foliated, is sometimes called *gabbro*.

This basic rock, doleryte, is what is ordinarily called *trap;* and sometimes, also, *basalt*. The name, *anamesite*, has been used for an aphanitic kind, but is unnecessary. The term *diabase* is sometimes applied to dolerytes *older than Tertiary*. It was formerly supposed that diabase, or the pre-Tertiary rock, differed from doleryte in being chloritic, and afterwards in not containing glassy particles: but neither distinction holds.

Eucryte is a doleryte-like rock consisting chiefly of anorthite and augite. Occurs compact and as a lava. *Teschenite* is bluish-green, and chiefly consists of anorthite, hornblende, and augite, the hornblende sometimes in large black prisms; also contains analcite; from Teschen, Austria.

8. AMPHIGENYTE (*Leucitophyre*). — Contains augite, like doleryte, but leucite (called sometimes amphigene) replaces the feldspar. Dark gray, fine-grained, and more or less cellular to scoriaceous. Sp. gr. 2·7–2·9. The leucite is disseminated in grains or in 24-faced crystals; constitutes the lavas of Vesuvius and some other regions.

9. NEPHELINYTE (Nepheline-doleryte). — Contains augite, like doleryte, but nephelite replaces the feldspar, or the larger part of it. Crystalline-granular; ash-gray to dark gray. The nephelite is partly in distinct crystals.

10. TACHYLYTE. HYALOMELAN. — Blackish glass, or pitchstone, made in connection with augitic igneous rocks or lavas; afford on analysis 49 to 55 five per cent. of silica.

3. CONTAIN CHRYSOLITE, AND LITTLE OR NO FELDSPAR.

1. DUNYTE. — Yellowish-green; granular. Consists of chrysolite, with some chromite. From Mount Dun, New Zealand.

2. LHERZOLYTE. — Greenish-gray; crystalline granular. Consists of chrysolite, enstatite, whitish pyroxene, with chrome-spinel and sometimes garnet. From Lake Lherz, etc. Is it metamorphic?

3. PICRYTE. — Blackish-green to brownish-red; crystalline-granular. Consists of chrysolite, with augite sometimes in crystals. Graduates into chrysolitic doleryte.

Limburgite is a semi-glassy rock of nearly similar composition. Affords on analysis 43 per cent. of silica.

II. CONDITION, STRUCTURE, AND ARRANGEMENT OF ROCK-MASSES.

The rock-masses of the globe, or *terranes*, as they are called, occur under three CONDITIONS: (1) the *stratified*, (2) the *unstratified*, and (3) the *vein* condition. Under each, there are peculiarities of STRUCTURE and of ARRANGEMENT.

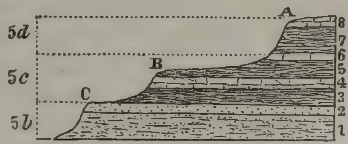
1. STRATIFIED CONDITION.

Under this head the subjects for consideration are, — 1. The nature of stratification; 2. The structure of layers; 3. The positions of strata, — both their natural positions and their dislocations; 4. The general arrangement of strata, or their chronological order.

1. *Nature of Stratification.*

Stratified rocks are those which are made up of series of layers or strata. The annexed sketch represents a section of the strata as exhibited along Genesee River, at the falls near Rochester. The whole height of the section is 400 feet. At bottom there is a thick stratum of sandstone (1); next above it lies a hard, gray layer (2), which has been called the *Gray Band*. On this rests (3) a thick bed of greenish shale, a fragile, imperfectly slaty rock. Next (4) is a compact limestone, forming a widespread stratum

Fig. 60.



resting on the shale. Above this (5) is another greenish shale, much like that below. Then (6) is another great stratum of limestone; then (7) another thick bed of shale; and, finally (8), at the top, is a limestone wholly different from those below. The transition from one stratum to another is quite abrupt; and, moreover, each may be traced for a great distance through the adjoining country.

Throughout far the larger part of America, as well as all the other continents, the rocks lie similarly in layers, so that stratified rocks are of almost universal distribution. They make up the mass of the Appalachians; cover nearly all of New York; underlie the great plains of the Ohio and Mississippi; occur over the larger part of the slopes and summit of the Rocky Mountains; along much of the Pacific border, as well as the Atlantic; and exist as red sandstone in the Connecticut valley. They are the prevailing rocks of Britain, including within their series the chalk, oölite, coal strata, and others. They occur over nearly all Europe, spread throughout the great plains of Russia, through Asia nearly to the tops of the Himalayas, over South America to some of the summits of the Andes, and through Africa and Australia. These stratified rocks are in striking contrast with the unstratified, — granyte, for example, which may show no appearance of layers even through heights of a thousand feet or more. Many volcanic masses of rock are unstratified. Yet the volcanic mountain has usually a *stratified* arrangement, successive layers of lava and volcanic sand or earth being piled up to make the cone. Even among crystalline rocks, the distinction of strata may often be made out, although much disguised by changes in the course of their history,

The succession of strata in stratified rocks is exceedingly various. In the section given, there are alternations of limestones, shales, and sandstone. In others, as at Trenton Falls, N. Y., there are only limestones in sight; but, were the rocks in view to a much greater depth, sandstone strata would be seen. In still other regions, there are alternations of conglomerates and shales; or conglomerates with shales and coal-beds; or conglomerates with limestones and sandstones; or shales and sandstones alone.

The thickness of each stratum also varies much, being but a few feet in some cases, and hundreds of feet in others; and the same stratum may change in a few miles from 100 feet to 10, or disappear altogether. In the Coal-formation of Nova Scotia there are 15,000 feet of stratified beds, consisting of a series of strata mainly sandstones, shales, and conglomerates, with some beds of coal; and in the Coal-formation of Pennsylvania there are 6,000 to 7,000 feet of similar character.

After these illustrations, the following definitions will be understood.

a. Stratification. — A succession of rock-layers, either of the same or of different kinds.

b. A *layer.* — A single member or bed in a stratified rock. It may be thick or thin, and loosely or strongly attached to the adjoining layers. In the section, Fig. 60, the limestones 4 and 6 consist of great numbers of layers; and in all limestone regions many are piled together to make the great mass of limestone.

c. A *stratum.* — The collection of layers of one kind which form a rock as it lies between beds of other kinds. In the section referred to (Fig. 60), the limestones 4, 6, and the shale masses 3, 5, 7, are each a *stratum.* A stratum may consist of many *layers.*

d. A *formation.* — A series of strata comprising those that belong to a single geological *age*, or to a single *period* or subdivision of an age, and which, consequently, have a general similarity in their fossils or organic remains. The *Coal-formation* includes many *strata* of sandstone, shales, limestones, and conglomerates.

Geologists speak of the Silurian formation, Devonian formation, Carboniferous (or Coal) formation, etc., making each cover a geological *age.* But they often apply the term also to subordinate parts of these formations. Thus, under Silurian, we have the *Upper Silurian formation,* and the *Lower Silurian formation;* and under each of these there are subordinate formations, as the *Trenton formation*, including the strata of the Trenton epoch in the Lower Silurian; the *Niagara formation*, for one of the lower sections of the Upper Silurian. These subdivisions embrace generally many strata, and have striking peculiarities in their organic remains; and hence this use of the word *formation.*

e. A *terrane.* — This term is used for any single rock or continuous series of rocks, of a region, whether the formation be stratified or not. It is applied especially to metamorphic and igneous rocks, as a *basaltic terrane*, etc.

f. A *seam* is a thin layer intercalated among the layers of a rock, and differing from them in composition. Thus, there are seams of coal, of quartz, of iron-ore. *Seams* become *beds*, or are so called, when they are of considerable thickness; as, for example, *coal-beds.*

These strata, which constitute so large an extent of the earth's crust, have been formed mainly by the action of water. As the ocean now makes accumulations of pebbles and sand, and muddy flats along its borders, and muddy bottoms for scores of miles in width along various sea-shores, so it formed, by the same means, many of the strata of sand and clay which now constitute the earth's rocks; and, in this work, the sea often had the advantage, in early times, of sweeping widely over the just-emerging continent. Again, as the rivers bring down sand and mud, and spread them in vast alluvial flats, making deltas about

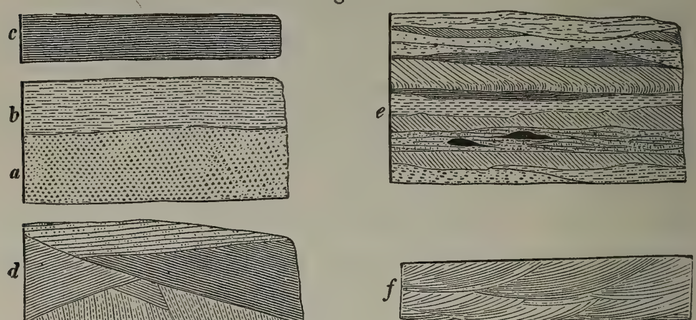
their mouths thousands of square miles in area, so in ancient time beds of sand and clay were accumulated by these very means, and afterward consolidated into rocks. Again, as shells and corals, by growing in the ocean where shallow, under the action of the waves, produce the accumulating and rising coral-reef some hundreds of miles long in the present age, so in former ages shells and corals grew and multiplied and made coral-reefs and shell-rocks, and these old reefs are the limestone strata of the world. The agency of water and life in these great results is particularly considered under Dynamical Geology.

2. *Structure of Layers.*

The structure of layers is due either to the original deposition of the material, or to subsequent changes.

(1.) **Kinds of structure and markings originating in the act or mode of deposition.**—The kinds of structure are illustrated in the annexed figures, and are as follow: *a*, the *massive;* *b*, the *shaly;* *c*, the *laminated;* *d*, *e*, and *f*, the *compound* or *irregularly bedded.* These terms,

Fig. 61.



excepting the last, have been explained (p. 63). Sandstones and conglomerates are often massive; but if argillaceous, or clayey, they are *laminated* like flagging-stone, and then are often called *flags.* A rock made of clay or fine mud is commonly *shaly.*

Beds consisting of thin and even subordinate layers, separable or not so, are said to be *straticulate.*

Compound structure is of different kinds.

a. Beach structure. — The upper part of a beach, above high tide level, is made by the toss of the waves, and especially in storms, and is generally irregularly bedded, as represented in the upper part of Fig. 61 *e.* But the lower part, swept by the tide, has usually an even seaward slope; and the beach deposits over it have therefore a corre-

sponding inclination — usually 5° to 8°, but sometimes steeper. When the sands are coral or shell sands, they become cemented into a calcareous sand-rock.

b. Ebb-and-flow structure — This kind of bed, although it be but a few feet thick, consists of layers of various kinds, some of which are horizontally laminated, and others *obliquely so*, with great regularity, as in Fig. 61 *e*. The succession indicates frequent changes in the currents during the deposition, such as attend the ebb and flow of tidal or river currents over a shallow bottom. The oblique lamination, observed in three of the layers of this figure, arises from a strong flow pushing up the sands before it.

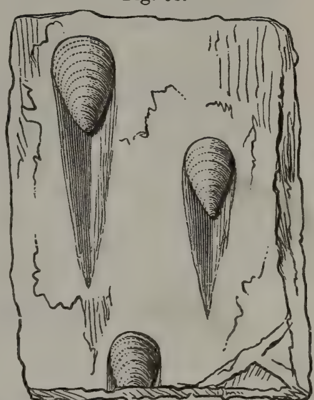
When the flow is accompanied by powerful waves or plunging of the water, the thrust at each plunge, besides bearing off part of what had before been laid down, deposits the sand in successive portions, as in Fig. 61 *f*, each obliquely and divergently laminated; each such portion is often two or three yards long and six inches or a foot thick, but varying much. Beds having this *flow-and-plunge structure* may alternate with others horizontal in bedding.

In obliquely laminated beds, the lamination dips in the direction in which the current moved.

c. Sand-drift structure. — The layers consist of subordinate parts dipping in various directions (Fig. 61 *d*), as if a laminated hillock made by sand drifted by the winds on a coast (for the sands of such drifts are always in layers) had been partly carried away, and then other layers had been thrown over it by the drifting winds at a new inclination, and

Fig. 62.

Fig. 63.



this violent removal and replacement had been often and variously repeated. Fig. 61 *d*, representing this mode of structure, is from Foster & Whitney's "Report on the Sandstone Rocks of Lake Superior." Fig. 61 *e* is also from the same work.

Besides these kinds of structure, there are *markings* in the strata which are of related origin, — viz.: ripple-marks, wave-marks, rill-marks, mud-cracks, and rain-drop impressions.

(1.) *Ripple-marks* (Fig. 62). — A series of wavy ridgelets, like the ripples on a sand-beach.

(2.) *Wave-marks.* — Faint outlinings on a sandstone layer, like the outline left by a wave along the limit where it dies out upon a beach, marking the outline of a very thin deposit of sand.

(3.) *Rill-marks* (Fig. 63). — Little furrows made by the rills that flow down a beach after the retreating wave or tide, and which become apparent especially where a pebble or shell lies, the rising of the water upon the pebble causing a little plunge over it and a slight gullying of the surface for a short distance.

Fig. 64.

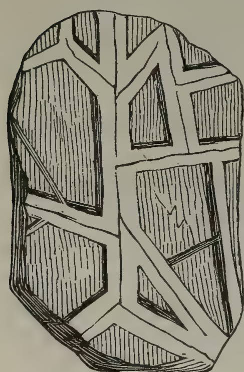
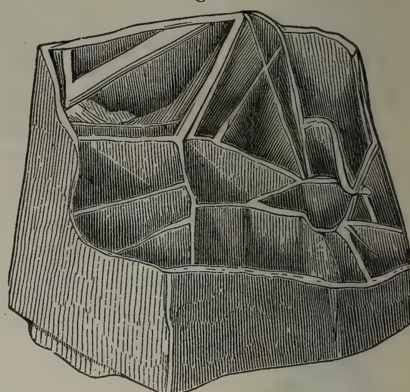


Fig. 65.

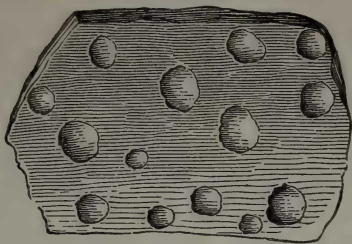


(4.) *Mud-cracks* (Figs. 64 and 65). — Cracks intersecting very irregularly the surface or a portion of a layer, and formed by the drying of the material of the rock when it was in the state of mud, just as a mud-flat left exposed to the drying sun now cracks. The original cracks are usually filled with a material harder than the rock, so that, when it becomes worn, the surface has a honeycomb appearance, from the prominence of the intersecting ridgelets, as in Fig. 65. Moreover, these ridges are generally double, the filling having been solidified against either wall of the crack until the two sides met at the centre and became more or less perfectly united. Specimens of rock thus honeycombed are sometimes called *septaria* (from *septum*, partition), but the term is little used in science.

(5.) *Rain-prints* (Fig. 66). — Rounded pits or depressions, made by drops of rain on a surface of clay or half-dry mud. On a reversed layer, the impressions appear raised instead of depressed, being casts made in the pits which the rain had formed.

(6.) There are also markings which are attributed to the *flowing of thick mud.* There are others, produced apparently by small eddyings

Fig. 66.

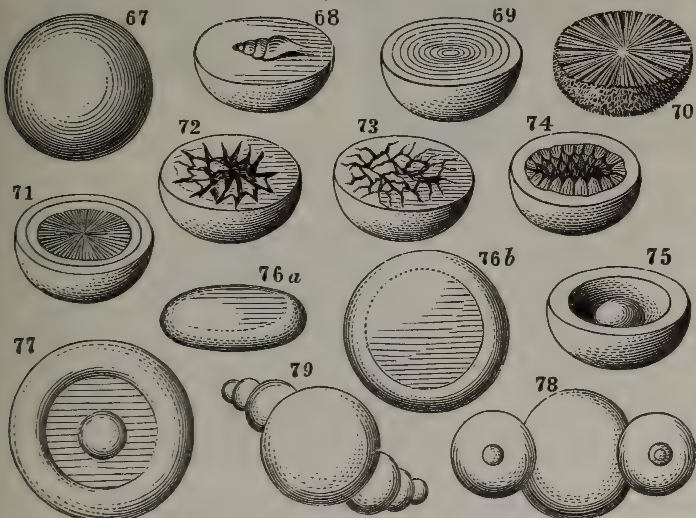


of water in clay or mud which work out concavities that afterward become filled with clay and look as if made by the valves of shells.

(2.) **Kinds of structure not properly a result of deposition, and mostly of subsequent origin.** — The kinds of structure here included are (*a*) the *concretionary*, (*b*) the *jointed*, and (*c*) the *slaty*. They are produced either in the process of consolidation or during subsequent changes.

a. The *Concretionary Structure.* — This kind of structure has been briefly explained on p. 63, and is here further illustrated. Concretions

Figs. 67–79.



in massive sandstones are usually spherical, but in laminated sandstones or shales more or less flattened.

Fig. 67 is a sphere, — a very common form. The sphericity is frequently as perfect as in a bullet, though the form is usually more or less ovoidal, and sometimes quite distorted. The size varies from a mustard-seed and less to a yard or more; and generally those that are together in a layer of rock approach a uniformity in size. They often have a shell, or a fragment of a plant, or some other object, at the centre. In other cases they are hollow and filled with crystals. The structure is often in concentric layers.

Figs. 68 to 75 are views of sections showing the interior. In 68 there is a fossil shell as a nucleus; in some cases a fossil fish forms the interior of a concretion.

The structure in Fig. 68 is solid without concentric layers. In Fig. 69, it is concentric. In 70, it is radiated or consists of crystalline fibres diverging from the centre and showing crystalline apices over the exterior surface. In Fig. 71, the exterior is concentric, but the interior radiated.

In Figs. 72, 73, the interior was cracked in drying; when these cracks are subsequently filled by carbonate of lime, heavy spar, or other material, by a process of infiltration, it becomes a kind of *septarium*, and is frequently beautiful when polished. In Fig. 74, the interior is hollow, and filled around with a layer of crystals (quartz crystals are the most common in such a condition), forming what is called a *geode*, — a little crystal grotto; but most geodes are not of concretionary origin. In Fig. 75 the concretion contains another small concretion; a variety not uncommon.

Figs. 76 *a*, *b* are different views of flattened or disk-shaped concretions; 77 is another, approaching a ring in shape; 78, 79, combinations of flattened concretions. Fig. 80 is

Fig 80.

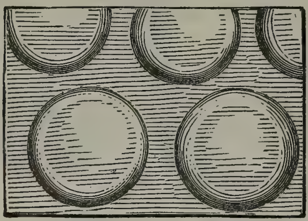
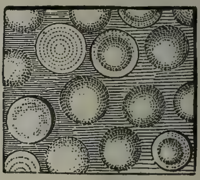


Fig. 81.



part of a clay layer made up of flattened concretions. A concretionary layer often graduates insensibly into one in which no concretions are apparent, through the coalescence of the whole. Fig. 81 represents a rock made up of concretions of the size of peas, — a calcareous rock called *pisolite* (from *pisum*, a *pea*). Each concretion has a concentric structure, the layers easily pealing off. Oölyte (named from ὠόν, egg) is similar, except that the concretions are in size like the roe of fish or even grains of sand.

Fig. 82 exhibits a crystalline rock with spherical concretions imbedded in its mass and not separable from it, — each layer (of the three represented in each concretion) consisting of different minerals: for example, *garnets* the centre, *feldspar* the middle layer, and *mica* the outer; and all making a solid mass. The constitution of such concretions is very various. In rocks containing feldspar, they usually consist largely of feldspar, and sometimes of feldspar alone, or of feldspar with some quartz. The concretions in pitchstone and pearlstone (called *spherulites*) are almost purely feldspathic, and often separate easily from the rock.

Fig. 83 represents basaltic columns, like those of the Giants' Causeway, having the tops concave: at each joint in the columns, in such a case, there would be the same concavity. This tendency to break with concave or convex surfaces has been attributed to a concretionary structure.

A *concentric structure* or condition often occurs which is not of concretionary origin. In Fig. 84, the two concentric areas in a sandstone (observed by the author in Australia) have together a diameter of twenty feet, and is made of concentric layers one half to two inches thick. They adjoin a fissure which admitted water; and the rusty bandings may

Fig. 82

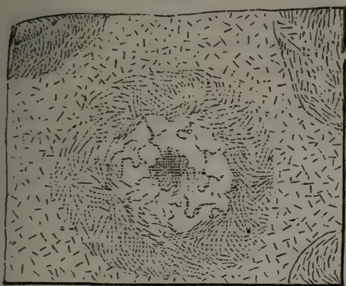
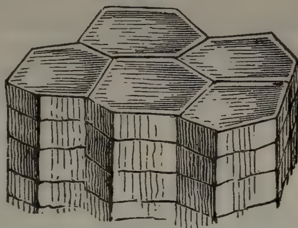


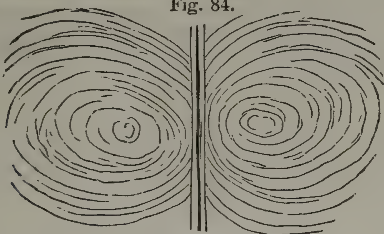
Fig. 83.



have been due to the oxidation of pyrite at the centre, and the spreading outward of the iron-bearing solution.

In other common cases, massive rocks that are much fissured or jointed, as some granite, doleryte, dioryte, etc., undergo easy decomposition as far as water can penetrate along the fissures.

Fig. 84.



As the process of oxidation goes on, the blocks into which the rock is divided by the fissures first have a colored border, and afterward become reduced to great rounded bowlder-like masses, with often a concentric banding in shades of brown (Fig. 85 A.).

Fig. 85.

Fig. 85 A.

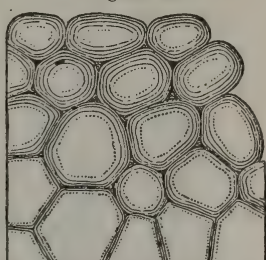
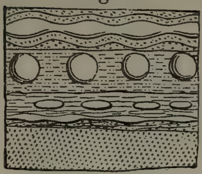


Fig. 85 is from an argillaceous sandstone which before consolidation had been intersected by slender mud-cracks, and subsequently, on hardening, each areolet became separately concentric. The *wear* of the sea had brought the structure out to view.

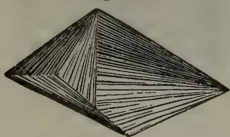
In Fig. 86, the lower sandstone layer (1) has no concretions; another (3) contains spherical concretions; in the upper layer (4), an argillaceous sandstone, the concretions are somewhat flattened and coalescent; in the shaly layer (2), they are very much flattened, and in its lower part coalescent.

Fig. 86.



A radiated arrangement is common when no distinct concretions are formed, as with quartz crystals in irregular cavities. Sometimes different points become centres of radiation, producing a blending of distinct radiations, as in Fig. 87.

Fig. 87.

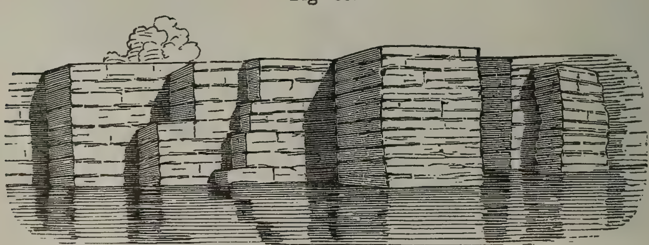


Very many of the mineral species shoot into stellar and globular radiated crystallizations. Others, like pyrites, readily collect in balls or nodules around a foreign body as a nucleus, or, if none is at hand, around the first molecule of pyrites that commences the crystallization. This tendency in nature to concentric solidification is so strong that no foreign nucleus is needed. The iron ore of coal-regions is mostly in concretions in certain layers of the Coal-measures. The rounded masses often lie imbedded in the clayey layer, or are so numerous as to coalesce into a solid bed.

Concretions sometimes take fanciful or imitative shapes; and every geologist has had petrified turtles, toads, human bones and skulls, brought him, which were only examples of the imitative freaks of the concretionary process. The turtles are usually what are mentioned as *septaria* on page 84. Occasionally concretions take long cylindrical forms, from consolidation around a hole bored by a worm or mollusk, the hole giving passage to the concreting ingredient; or they derive their form from some rootlet or stem of a plant, in which case they are often branched; or they were stalactites descending from the roof of a cavity.

b. The *Jointed Structure.* — *Joints* in rocks are planes of fracture or *divisional planes* cutting directly across the stratification and extending through great depths. The planes of division are often perfectly even, while they may not be open enough to admit the thinnest paper. These *joints* may be in one, two, or more directions in the same rock, and they often extend, with nearly uniform courses, through regions that are hundreds of miles in length or breadth. The accompanying sketch represents the falling cliffs of Cayuga Lake, and the

Fig. 88.

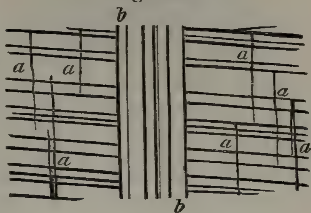


fortress-shapes and buttresses arising from the natural joints intersecting the rocks. The wear of the waters from time to time tumbles down an old surface, and exposes a new range of structures.

Traversing the surface of a region thus intersected, the joints appear as mere fractures, and are remarkable mainly for their great extent, number and uniformity. In case of two systems of joints, — the case most common, — the rock breaks into blocks, which are rectangular or rhomboidal, according as the joints cross at right angles or not. The main system of joints is usually parallel to the strike of the uplifts, or else to the range of elevations or mountains in the vicinity, or to some general mountain-range of the continent; and the directions are studied with much interest, because of their bearing upon the geological history of the country.

In many cases, a rock is so evenly and extensively jointed as to become thereby laminated, and in such a case the joints may be easily mistaken for planes of stratification, especially when the latter have been obliterated. Sometimes there are sudden transitions from the regular stratification to vertical joints, as in Fig. 88 A. This case occurs in a section of part of a quartzyte bluff on the railroad near Poughquag, Dutchess Co., N. Y. *a, a, a,* are ordinary joints in the stratified rock; *b, b,* is a portion of the rock, which has lost its stratification entirely, and has become jointed vertically; the transition from the stratified to the part *b, b,* is so abrupt that the latter has the aspect of an intersecting dike, or of a portion of the laminated sandstone set erect.

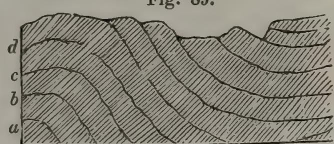
Fig. 88 A.



c. The *Slaty Structure.* — The slaty structure or slaty cleavage, as it is called — is in some cases parallel with the planes of deposition or bedding of a rock; and such examples of it come under a former head. But in many of the great slate regions, as in that of Wales, the slate lamination is transverse to the bedding, as shown in Fig. 89, in which the lines *a, b, c, d* show the lines of bedding, and the oblique lines the direction of the slates. Whole mountains have sometimes this kind of oblique or transverse lamination.

The sketch, Fig. 89, by Mather, is from the slate region of Columbia County, N. Y.

Fig. 89.



Occasionally, the lines of deposition are indicated by a slight flexure in the slate near them, as in Fig. 90. In other cases, there is a thin intermediate layer which does not partake of the cleavage. Fig. 91 represents an interstratification of clay-layers with limestone, in which the former have the cleavage, but not the latter, — though the limestone sometimes shows a tendency to it when argillaceous. Fig. 92 represents a rock with two cleavage-directions; and

Fig. 90.

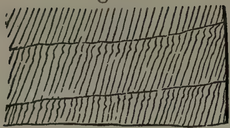
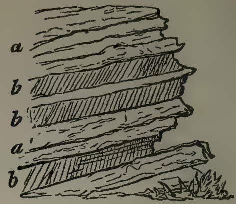


Fig. 91.



93, a quartzose sandstone which has irregular cleavage-lines. These last two cases, together with that represented in Fig. 88 A, show that the jointed structure and cleavage-structure have the same origin.

Fig. 92.

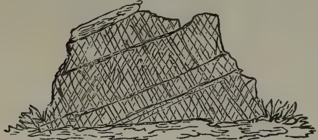
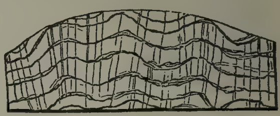


Fig. 93.

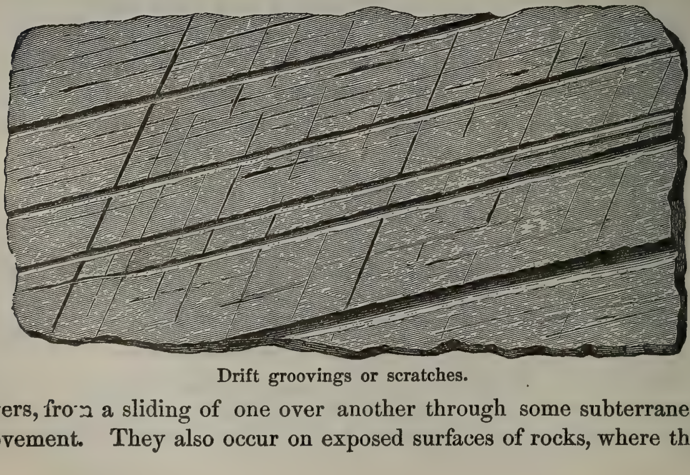


Sedgwick first detected the true lines of bedding, and ascertained that the slaty structure was one that had been superinduced upon the clayey strata by some process carried on since they were first deposited.

Foliation. — The foliated structure (or *foliation*) of mica schist, gneiss, and related schistose rocks may sometimes be transverse to the bedding, like most slaty cleavage. But it is not generally so.

(3.) **Markings which result from movements of rocks.** — *Grooving and planing*, and often *polishing*, of rock surfaces occur in the walls of fractures (as those of veins, for veins occupy fractures), which have resulted from the friction of one wall against the other, usually produced when the fracture was made; and sometimes on the surfaces of

Fig. 93 A.



Drift groovings or scratches.

layers, from a sliding of one over another through some subterranean movement. They also occur on exposed surfaces of rocks, where they

have been made by stones, gravel, or sand, transported by the winds, water, or ice, or by any other cause of movement. Figure 93 A represents scratches made by glacial action.

3. *Positions of Strata.*

The natural positions of strata as formed, and the positions resulting from the disturbance or dislocations of strata, are two distinct topics for consideration in this place.

1. **The natural positions of strata as formed.** — Strata in their natural positions are commonly horizontal, or very nearly so. The level plains of alluvium and the extensive delta and estuary flats show the tendency in water to make its depositions in nearly horizontal planes. The deposits formed over soundings along sea-coasts are other results of sea-action; and here the beds vary but little from horizontality. Off the coast of New Jersey, for eighty miles out to sea, the slope of the bottom averages only 1 foot in 700, — which no eye could distinguish from a perfect level. As the processes of the present period along coasts illustrate the grand method of rock-accumulation in past time, it is plain that strata, when in their natural positions, are very nearly, if not quite, horizontal. Over a considerable part of New York and the States west and southwest, and in many other regions of the globe, the strata are actually nearly horizontal at the present time. In the Coal-formation, the strata of which have a thickness, as has been stated, of five to fifteen thousand feet, there is direct proof that the beds were horizontal when formed; for in many of the layers there are fossil trees or stumps standing in the position of growth, and sometimes several of these rising from the same layer. Fig. 94 represents these tilted coal-beds *c*, *c*, with the stumps *s*, *s*, *s*. Since these trees must have grown in a vertical position, like all others, and as now they are actually at right angles to the layers, and parallel to one another, they prove that the beds originally were horizontal. The position of shell-accumulations and coral-reefs in modern seas shows, further, that all limestone strata must have been nearly or quite horizontal when they were in the process of formation.

Fig. 94.

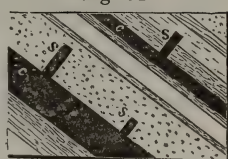
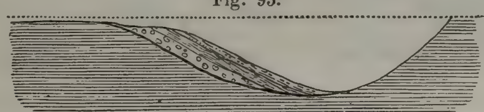


Fig. 95.



In sedimentary deposits, however, some *variation from horizontality*

may be produced by the slope of the sea-bottom in certain cases; and, off the mouths of rivers, in lakes (Fig. 95), quite a considerable inclination may result from the fact that the successive layers derived from the inflowing waters have taken the slope of the bottom on which they fell. The sand deposits made over the slope of a sea-beach between low and high tide are another example; they take the slope of the beach, as stated on page 82. Cases of inclined position from this cause are necessarily of limited extent, since the conditions required are not likely to exist on a large scale.

It follows from these facts, that, unless strata have been disturbed from their natural positions, *the order in which they lie is the order of relative age,— the most recent being highest in the series.*

(2) **Dislocations of strata.** — Strata, although generally in horizontal positions when formed, are often, at the present time, *tilted*, or inclined, and the inclinations vary from a small angle to verticality, or even beyond verticality. They have been raised into folds, each fold often many miles in sweep and equal to a mountain-ridge in extent. They have been crumpled up into groups of irregular flexures, one fold or flexure succeeding to another, till like a series of wrinkles — and necessarily coarse wrinkles — on the earth's surface. Every mountain-region presents examples of these flexures; and most intermediate plains have at least some undulations in conformity with the system in the mountains.

In connection with all this uplifting, there have been fractures on a grand scale; and strata thus broken have been displaced or dislocated by a sliding of one side of such a fracture on the other, through varying distances from a few feet to miles,— one side dropped down to this extent, or the other side shoved up.

The subject of the dislocations of strata is hence an important one in Geology.

Uplifts, Folds, Dislocations. — The following sections illustrate the general facts respecting these uplifts, dislocations, and folds.

Fig. 96.

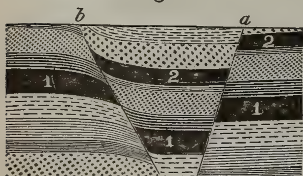


Fig. 97.

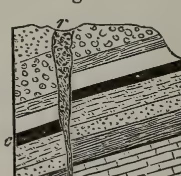


Fig. 97 A.

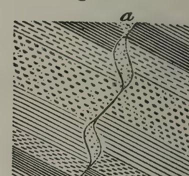


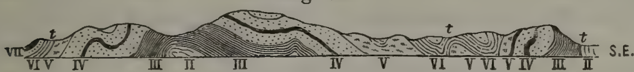
Fig. 96 represents a part of the Coal-formation, dislocated along the lines of fracture *a a* and *b b*, the beds (the coal-beds 1 and 2 and the other layers) being displaced as well as disjoined in the fracturing.

Such a dislocation along a fracture is called a *fault.* Faults vary from an inch or less of displacement to thousands of feet. Along the line *b b*, there is not only a fault, but also at the junction a bending of the layers, arising from the friction of one side against the other when the dislocation took place. In Fig. 97, the fracture is an opened one filled with rock. In 97 A, the fracture was a crooked one, and consequently the sliding of one side on the other left a series of open spaces to become subsequently filled. On p. 111, other faults are represented.

Folds or *flexures* are most common in the rocks of mountainous regions. They show that, in mountain-making, rock-formations have been bent as sheets of wax may be bent. Single folds are often miles in span, scores of miles in length, and thousands of feet in height. A ridge sometimes corresponds to one such fold. On the other hand, a stratum may have its bed bent into small zigzags or contortions, like those of Fig. 99 E. The large folds are not now entire because most upturned rocks are easily worn away by flowing waters; but their original forms are indicated by the inclinations of the strata that remain.

Fig. 98, by Rogers, is from an actual section in the Appalachians,

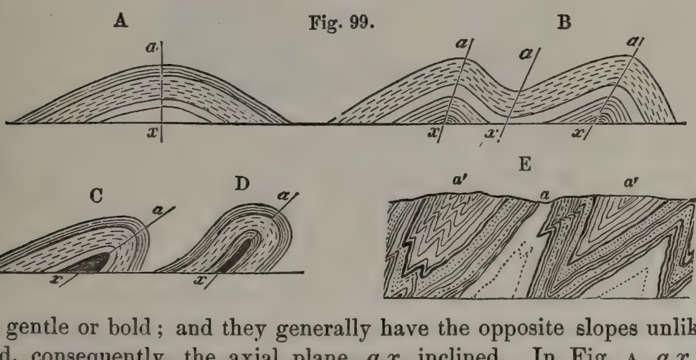
Fig. 98.



six miles in length, and shows the foldings of the strata. These are numbered so that the bendings of a given stratum may be followed. Thus III bends over II, to the left of the middle of the figure, and the right portion descends to come up again in III at the right end of the figure; again, IV, to the left, rises and bends over III and II, though disjoined about the top of the fold by denudation.

Flexures, as illustrated in the transverse sections, Fig. 99 A–D, may

Fig. 99.



be gentle or bold; and they generally have the opposite slopes unlike, and, consequently, the axial plane, *a x*, inclined. In Fig. A, *a x* is nearly vertical; but in B, C, D, it is much inclined. In D, the top of

the fold overhangs the base, and the pitch of the beds on the right is thereby *reversed*, so as to be like that on the left. In rare cases, an abrupt fold has been so compressed below that the beds above diverge fan-like.

Fig. 100 represents a section (by Heim, p. 833) from the Swiss side

Fig. 100.

Section east of L. Lucerne, extending south, 15 m., through Windgälle (4, to the right), a peak 10,455 feet high; 1, Gneiss; 2, Triassic beds; 3, Lias; 4, Jurassic, above the Lias; 5, Cretaceous; 6, Eocene Tertiary, including Nummulitic beds.

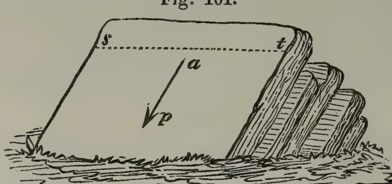
of the Central Alps. To the right, the strata, 1, 2, 3, 4, 6, are in an *overturn* fold, the newest, 6, beneath 4, 3, 2, 1, with 1, the oldest, at top. Through the dotted lines, the forms of the folds in the section may be traced. For other sections, see pp. 212 to 214, 346, 399, 785 to 790.

The ridge-line of a fold is usually inclined, and unequally, either way; and when this inclination is large, the steeper end of the fold is generally wanting because of removal by denudation. See Fig. 108, p. 98.

113. In describing strata, the following terms are used:—

a. Outcrop.—A ledge or mass of rock coming to the surface, or cropping out to view at the surface or above it (Fig. 101). Outcropping edges are sometimes called *basset-edges.*

Fig. 101.



b. Dip.—The slope or pitch of the strata, or the angle which the layers make with the plane of the horizon; as *a p* (Fig. 101). The *direction of the dip* is the point of the compass toward which the strata slope; for example, the *dip* may be 25° *to the southeast*, or 15° *to the west*, and so on.

c. Strike.—The direction at right angles with the dip, or the course of a horizontal line on the surface of the inclined beds, as *s t*.

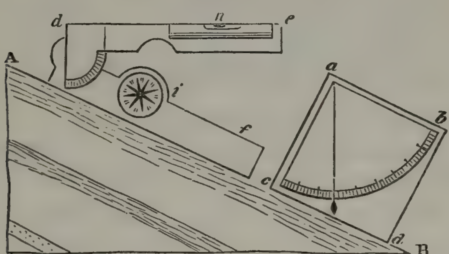
The *strike* and *dip* are always observed with care, in the study of strata; for the *strike* is in general at right angles approximately to the direction of the force that upturned the beds, and indicates therefore an important fact with regard to the origin of the upturning; and the *dip* is but little less important, since it illustrates the amount

and character of the upturning. In making observations, see (1) that the outcrop is not that of a bowlder; or (2) of layers displaced by the growing roots of trees or otherwise; also whether (3) the dip and strike are those of merely local or superficial flexures, or of the great and general bendings of the rocks. Also consider (4) that, when one fold dies out and another begins at the same time to rise on one side or the other, there will be, as a consequence, transverse strikes over the region between the approximate ends of the two folds. As all folded strata were once horizontal, the study of the flexures of strata is the study of bent or warped surfaces; and the results of observations cannot be right unless they are consistent with one another in this view.

d. Anticlinal, Synclinal. — In folded strata, the layers bend *upward* and *downward* successively; the *upward* is an *anticlinal* flexure (from ἀντί, *opposite*, and κλίνω, *I incline*), and the *downward* a *synclinal* (from σύν, *together*, and κλίνω). In the *anticlinal* (Fig. 99, A, C, D, and either summit of B), *a x* is the *anticlinal axis*, or that *away from* which the layers slope; and in the *synclinal* (middle part of Fig. 99 B), *a′ x′* is the *synclinal axis*, *toward* which the layers slope. In Fig. 99 E, *a* marks the position of an anticlinal axis, and *a′*, *a′* those of two synclinal axes. The roofs of ordinary houses are examples of anticlinals, and the ridgepole has the direction of the anticlinal axis. If the ridge-line of a fold is inclined, then the anticlinal axis is said to be inclined. In a *monoclinal*, the beds dip in one direction (p. 792).

The *dip* and the *direction* of the *strike* are ascertained by means of an instrument called a *clinometer*, which is in part a pocket compass. A common kind is a pocket compass of the size of a watch, having a pendulum at centre to note by its position the angle of dip. The best has a diameter of 3¾ inches, and a square base whose sides are parallel to the principal diameters of the circle. The part of Fig. 102 to the right illustrates the use of the pendulum, and shows how a

Fig. 102.



cheap form of clinometer may be made. On placing the side *c d* on an inclined plane (A B), the angle is marked by the position of the pendulum, which of course hangs vertical. Another kind of clinometer is shown in the upper part of the same figure.

When only the under surface of projecting strata can be reached, the upper side of the instrument (*a b*, in Fig. 102) should be applied to the rocks. By holding the instrument between the eye and the sloping outline of a distant hill or mountain, making *a b* or *c d* coincide with this outline, the angle of slope may be measured. The *strike* of inclined strata, when they are seen in profile, may be taken by holding the instrument with the edge *a b* horizontal (as ascertained by the pendulum), and then sighting along *a b* and finding thus a point on the edge of the sloping layers (or in the line of such an edge produced downward, if the rocks are above the level of the eye); the direction of this point is the *strike*. Then, by making the edge *a b* to coincide, by sighting across, with the slope of the layers, the *dip* may be taken. Before applying a clinometer to a layer of rock, a strip of board should be placed upon the layer, so that any unevenness of the surface may not lead to error.

The directions obtained by a compass will always need correction for the magnetic variation.

Faults.—The term fault is defined on p. 93. In Fig. 96, the parts of each faulted bed are of equal thickness on the two sides of the line of fault. When, in a dislocation, there is a *lateral* or *oblique* shove, as is often the case, the thickness may differ, provided the bed is not throughout of uniform thickness. This difference of thickness may indicate a lateral movement when there is no proof of a vertical.

Complexities in stratified deposits arising from denudation and other agencies.— By the denuding action of waters, strata are removed over

Fig. 103.

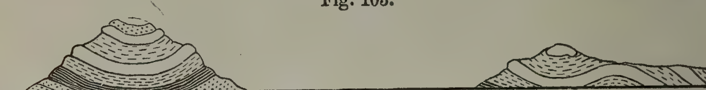


Fig. 104.

extensive territories, the tops or sides of folds are carried away, and various kinds of sections made of the stratified beds, which are often perplexing to the student.

One of the simplest of these effects is the entire removal of the rocks over wide intervals, so that the continuation of a stratum is met with many miles distant, as in Figs. 103, 104.

The result is more troublesome among the flexed or folded strata. A series of close flexures, like Fig. 105, worn off at top down to the

Fig. 105.

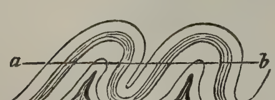


Fig. 106 *a*.

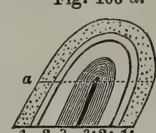


Fig. 106 *b*.

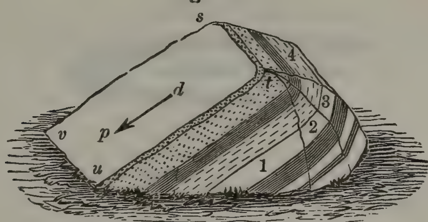
line *a b*, loses all appearance of folds, and seems like a series of layers dipping in a common direction. This is best seen from a single fold

(Fig. 106 *a*). If the part above the line *a b* were absent, the five layers would seem to be a single regular series, with 1 as the top layer, 3,3′ the middle, and 1′ the bottom one ; while the fact is that 1 and 1′ are the same layer, and 3,3′ is actually a double one. In a number of such folds, the same layer which is made two in one fold would be doubled in every other, so that in a dozen folds there would seem to be twenty-four, when in fact but *one.* A mistake as to the order of succession would therefore be likely to be made, also as to the number of distinct layers of a kind, and also as to the actual thickness of the middle layer. Instances of a coal-layer doubled upon itself, like 3,3′, and of others made to appear like many distinct layers, occur in Pennsylvania. On this point special facts are mentioned in the section on the Coal formation.

Other effects of denudation are exemplified in Fig. 98, page 93. The stratum No. III. is a folded one, with its top partly removed; the layers within a short distance dip in opposite directions. The layer No. IV., as has been explained, is widely disjoined. Again, V. lies upon the top of the highest summit, nearly horizontally, and in a shallow basin: yet it is part of the stratum V. to the left, which is obviously much folded. The observer finds it necessary to study the alternations of the beds with great care, in order to succeed in throwing into system all the facts in such a region. The coal-regions of Pennsylvania, the whole Appalachians, all New England, and much of Great Britain and Europe, illustrate these complexities arising from flexures and denudation.

There is difficulty also in ascertaining the true dip of strata from exposed sections. In Fig. 107, *s t u v* is the upper layer of an out-

Fig. 107.

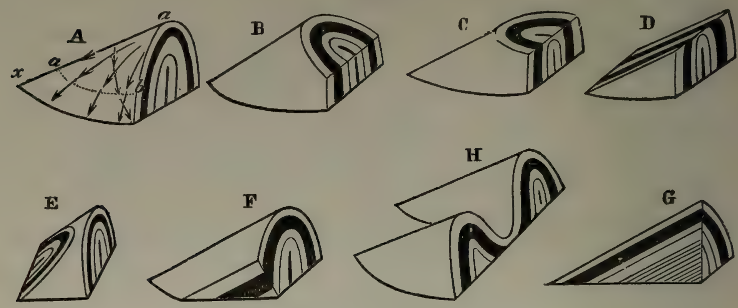


cropping ledge of rock, *d p* the line of dip, *s t* the strike. The ledge shows four sections 1, 2, 3, 4. On 1, the edges have the same dip as *d p* ; but, on 2, 3, and 4, the angle as obtained from the exposed edges would be different; and on the last, the edges would be horizontal or nearly so. Thus all sections except the one in the direction of the true line of dip (or at right angles to the *strike*) would give a false dip. By finding the surface of a layer exposed to view, the true direction of the dip or slope may be ascertained, and the error avoided.

The following figures (Fig. 108) still further illustrate this subject, by showing the variations of direction that may be obtained from the sections of a single folded ridge. For simplicity of explanation, the fold is supposed to be a symmetrical one, though

with the ridge-line or anticlinal axis ($a\,x$ in A) inclined. In A the section is vertical; and neither the true dip nor strike corresponds with the direction of the edges; the dip

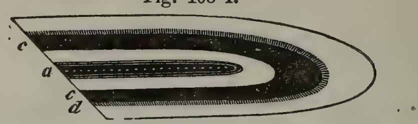
Fig. 108.



has the direction of the arrows, and the strike that of the outline of a horizontal section, as $a\,b$ in the same figure. In B the section is very obliquely inclined; in C it is horizontal, and the edges show nothing of the actual dip; in D the section follows the line of strike; in E it is oblique behind; in F it is an oblique section on one side; and in G a vertical section in the axial plane. All of these sections give wrong results to the clinometer, — a section in the direction of the arrows in Fig. A being the only one in which the dip of the exposed edges is the dip of the layers or strata. See also p. 869.

If the axis of the fold make a very small angle with the horizon, then the two sides in a horizontal section (such as may result from denudation) will be much elongated as in Fig. 108 I, instead of short as in Fig. C; and if the axis is horizontal the two sides will not meet at all, and the fact of the existence of a fold is not apparent. Even in the former case there might be difficulty in determining the fact of a fold, if the part

Fig. 108 I.



where the sides unite were concealed from view by the soil or otherwise. But in each case there may be evidence of a fold in the order of the beds on the two sides; for this order on one side would be just the reverse of that on the other. If, in Fig. 108 I, $c\ c$ represent a coal or iron-ore bed having its border d more impure than the rest, this border, if it were on the east side in one half of the fold, would be on the west side in the other half.

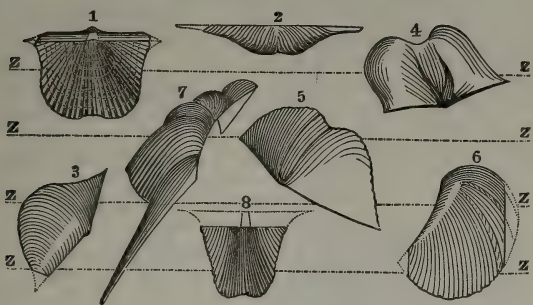
The difficulties in the way of correct observation on folded rocks are further enhanced when the axial plane of the fold is inclined, — especially when it is so inclined that both sides of the fold have the same dip (Fig. 106 a). Still closer study is required when several folds are irregularly combined, as is common in nature.

This important subject may be further studied by uniting sheets of differently-colored card-board together, bending them into a fold, and then cutting them through in different directions.

Distortions of fossils. — Uplifts of the rocks, besides disturbing the strata themselves, cause distortion in imbedded fossils, — either (1) a flattening from simple pressure; or (2) an obliquity of form; or (3) a shortening; or (4) an elongation.

The following figures, from a paper by D. Sharpe, illustrate some of these distortions occurring in a slate rock in Wales. They represent two species of shells, the *Spirifer disjunctus* (Nos. 1 to 4) and the *Spirifer giganteus* (Nos. 5 to 8). No. 1 is the natural form of *S. disjunctus;* the others are distorted. The lines *z z* show the lines of cleavage in the slate: 2 lay in the rock inclined 60° to the planes of cleavage, and is shortened one-half: 3 lay obliquely at an angle of 10° or 15°; it is shortened above the middle and lengthened below it: 4 is a cast, the upper part pressed beneath that shown, while the lower is much drawn out: 5 is like 3, the angle with the cleavage-plane being less than 5°; the lower part has lost its plications by the pressure and extension: 6 has a similar angle to the cleavage-plane, but a different position: 7 intersects the cleavage-plane at only 1°, and its lower part is very much prolonged. Compression, a sliding of the rock at the cleavage-planes, and more especially a spreading of the rock itself under the pressure, are the causes which have produced these distortions. All fossils are liable to become similarly misshapen under the same conditions.

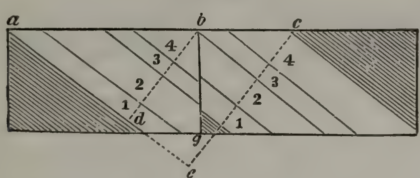
Fig. 109.



Calculating the thickness of strata.—When strata are inclined, as in Fig. 110, the thickness is ascertained by measuring the extent along the surface, and also the angle of dip, and then calculating the thickness by trigonometry. The thickness of the strata from *a* to *b* is *b d*, the line *b d* being drawn at right angles to the strata. Measuring *a b*, and the dip, which is the angle *b a d*, the angles and hypothenuse of the triangle *a b d* are given to determine one side *b d*. Or, with the distance *a e*, the side *c e* would be found.

But it is important, for trustworthy results, that the absence of

Fig. 110.



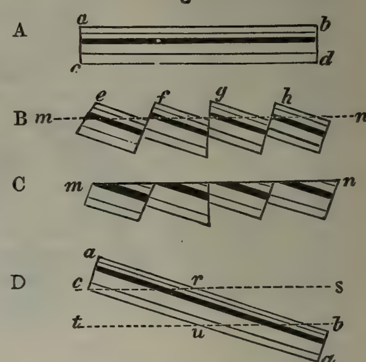
faults be first ascertained. The figure (110) represents a fault at *b g*, so that the strata 1, 2, 3, 4 to the left are repeated to the right; and

hence the whole thickness is *b d* instead of *c e*. There may be many such faults, in the course of a few miles; and each one would increase the amount of error, if not guarded against.

It is seen, from Fig. 110, that a single inclined stratum consisting of the layers 1, 2, 3, 4 would have a surface-width (width at the earth's surface or on a horizontal plane) of *a b*. But, by means of the fault, another portion is brought up to the surface, and *a b* is increased to *a e*.

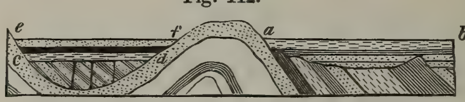
So other faults might go on increasing the extent of the surface-exposure. This is further illustrated in Fig. 111. Let A be a stratum 10,000 feet thick (*a* to *c*) and 100,000 feet long (*a* to *b*). Let it now be faulted as in Fig. B, and the parts uplifted to a dip of 15°, — taking a common angle for the parts, for the sake of simplicity of illustration. The projecting portions being worn off by the ordinary processes of denudation, it is reduced to Fig. C, *m n* being the surface exposed to the observer. The first error that might be made from hasty observation would be that there were four distinct outcropping coal-layers (calling the black layer thus), instead of *one;* and the second is the one above explained with regard to calculating the thickness of the whole stratum from the entire length *m n* in connection with the dip. If the stratum were inclined at 15° without faulting, it would stand as in Fig. D; and, if then worn off to a horizontal surface, the widest extent possible would be *c r*, — less than half what it has with the three faults.

Fig. 111.



Conformable and unconformable strata. — Strata are *conformable*, when they conform to one another in superposition, that is, lie one over the other with the same dip; and they are *unconformable* when one overlies the upturned edges of another stratum, with no conformity in dip or position. Fig. 112 represents cases in which, after

Fig. 112.



the rocks below had been folded or upturned, other strata were laid down at *a b* and *e f* horizontally on the *inclined* beds; these are examples of *unconformability*. Below *e f*, there are really two sets of *unconformable* beds in a synclinal valley; and, moreover, the lower strata were much faulted and upturned, before the upper were laid down upon them. The Connecticut River sandstone, like the latter,

lies on upturned older rocks, is more or less faulted, and is overlaid by horizontal alluvial beds.

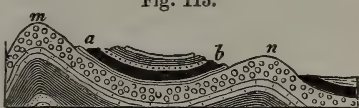
In such cases of *unconformability*, the upturning of the lower beds must have taken place before the deposition of the overlying beds. The *time of the upturning*, therefore, was between the period to which the upturned rocks belong and that of the overlying deposits.

When, after the deposition of beds in a continental sea, or along its borders, a sinking of the region takes place, the next deposits there made would extend beyond the limits of the preceding, and overlap on those outside. In such cases, although both deposits are approximately horizontal, there is still a kind of unconformability called an *overlap*.

When strata are faulted, there may be perfect *conformity of dip* between the beds either side of the fault, as in Figs. 110 and 111 C, and yet no *conformability*, since this relates to *superposition*. So there may be *unconformity* as to *dip* on two sides of a fault without *unconformability*. It is easy to be led astray by such appearances of unconformability, especially in regions of metamorphic rocks. Actual superposition must be seen, before the fact of unconformability can be safely asserted.

Deposits like those at *e f* are true *basin*—or *trough*—*deposits*; for they are formed in basins or depressions of the surface. Such deposits may, in general, be distinguished by their thinning out toward the sides of the basin. Yet, when synclinal valleys are shallow, it is easy, and not uncommon, to mistake beds conformable with the strata below for such basin-formations. The beds *a b* (Fig. 113) lie in the synclinal valley *m n*, like a basin-deposit, though not so. They were formed *before* the folding of the beds, and not *after* it,—an historical fact to be determined in all such cases with great care.

Fig. 113.



4. *Order of arrangement of Strata.*

The true order of arrangement of strata is the order in which they were made, or their *chronological order*. All strata of the same era, as nearly as can be ascertained, are said to be *equivalent* strata, or those of the same *geological horizon*.

As geological eras, even the shorter divisions, have in general been of very long duration, the *equivalent* strata of distant regions cannot be known to be precisely synchronous in origin. A long time, measured by thousands of years, may in fact have intervened between the commencement of beds that are most alike in all those points by which we determine age and equivalency.

Huxley, in view of the impossibility of determining true synchronism, has proposed to designate by the term *homotaxial* (from the Greek ὁμός, *same*, and τάξις, *order*) those strata, in regions more or less widely separated, that have apparently the same relative position in the geological series.

Difficulties.—The following are some of the difficulties encountered in the attempt to make out a chronological order:—

The stratified rocks of the globe include an indefinite number of

limestones, sandstones, shales, and conglomerates; and they occur horizontal and displaced; conformable and unconformable; part in America and part in Europe, Asia, and Australia; here and there coming to view, but over wide areas buried beneath soil and forests.

Moreover, even the same bed often changes its character from a sandstone to a shale, or from a shale to a limestone or a conglomerate, or again to a sandstone, within a few miles or scores of miles, and sometimes within a few rods; or, if it retains a uniform composition, it changes its color so as not to be recognized by the mere appearance. In the United States, many a sandstone in New York and Pennsylvania is represented by a limestone in the Ohio and Mississippi valleys, — that is, the two were of cotemporaneous origin; some rocks in eastern New York are not found in the western part of that State, and some in the central and western not in the eastern.

In all eras, sand-beds, mud-beds, clay-beds, pebble-beds, and limestone-beds have been *simultaneously* in progress over different parts of the globe; and, if an era is known in geology as solely an era of limestone, it is because science has not yet discovered where the beds of sand, mud, or pebbles of that era were being deposited while the limestone was making over its regions. The idea of an era of sandstone making, or of limestone making, is therefore an absurdity; for sand deposits are local; a short distance off, there may have been, in all times, as now, mud deposits. Still, it is true that, over continental seas, the *prevailing* depositions have sometimes been of limestone material, and sometimes of mud or sand; yet this has been true for certain great regions in the seas of a continent, rather than for all its seas at once.

Again, a stratum of one age may rest upon any stratum in the whole of the series below it, — the Coal measures on either the Archæan, Silurian, or Devonian strata; and the Jurassic, Cretaceous, or Tertiary on any one of the earlier rocks, the intermediate being wanting. The Quaternary in America in some places rests on Archæan rocks, in others on Silurian or Devonian, in others on Cretaceous or Tertiary. And, if so great diversity of condition exists in one country, far greater may be expected between distant continents.

In addition, denudation and uplifts have thrown confusion among the beds, by disjoining, disarranging, and making complex what once was simple.

Amidst all these sources of difficulty, how is the true order ascertained?

Means of determination. — It is plain, from the preceding remarks, that the true method cannot consist in grouping rocks of a kind together, as limestones, shales, or sandstones. It is irrespective of kinds, and is founded on a higher principle, — the same which is at the basis

of all history, — successiveness in events. The following are the means employed.

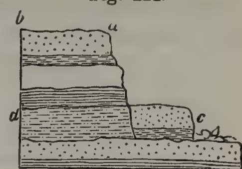
(1.) *Order of superposition.* — When strata are little disturbed, vertical sections give the true order in those sections, and afford valuable information. Or, where the strata outcrop over the surface of a country, the succession of outcropping layers affords a section, and often one of great range. The vertical extent of such a section may be ascertained as explained on p. 99. In using this method by superposition, several precautions are necessary.

Precaution 1st. — Proof should be obtained that the strata have not been folded upon one another, so as to make an upper layer in any case a lower one in actual position (see p. 97), — a condition to be suspected in regions where the rocks are much tilted, but not where the tilting is small.

Precaution 2d. — It should be seen that the strata under examination are actually continuous.

A fault in the rocks may deceive; for it makes layers seemingly continuous which are not so. Such faults are common, and often extensive, in regions of upturned or much displaced rocks, and may occur when the dip is slight. In some cases, beds forming the upper part of a bluff (as *a b*, Fig. 114) have settled down bodily (*c*) to the bottom, so as to seem to be continuous with the older ones of the bottom (as *c* with *d*). In other cases, caverns in rocks have been filled through openings from above, and the same kind of mistake made. When the continuity can be established, the evidence may sometimes lead to unexpected results. For example, it may be found that a coal-bed, followed for some miles to one side or the other, is continuous with a shale, and both are actually one layer; that a sandstone is one with a limestone a few miles off; that an earthy limestone full of fossils is identical with a layer of white crystalline marble in a neighboring district; or that a fossiliferous shale of one region is the same stratum with the mica schist of another.

Fig. 114.



Precaution 3d. — Note whether the strata overlie one another *conformably* or not.

Precaution 4th. — Remember that, where one bed overlies another conformably, it does not follow necessarily that they belong to *consecutive* periods, as has been above explained.

The criterion mentioned, unless connected with others, gives no aid in comparing the rocks of distant or disconnected regions. For this purpose, other means must be employed.

(2.) *Color, texture, and mineral composition.* — This test may be used to advantage within limited districts, yet only with caution. There were at one time in geology an "old red sandstone" and a "new red sandstone;" and, whenever a red sandstone was found, it was referred at once to one or the other. But now it is well understood that color is of little consequence, except within a small geographical range.

The same general remark holds with reference to mineral composition, as explained on page 102.

One inference from the mineral constitution of a stratum is safe; that is, that *a stratum is more recent than the rock from which its material was derived.* Hence, an imbedded fragment of some known rock may afford important evidence with regard to the age of the containing stratum.

The age of metamorphic and igneous rocks is sometimes judged of on lithological evidence; but, with possibly some exceptions among Archæan metamorphic rocks, the criterion is worthless.

(3.) *Fossils.* — This criterion for determining the chronological order of strata takes direct hold upon time, and, therefore, is very much the best. *The life of the globe has changed with the progress of time. Each epoch has had its peculiar species.* Moreover, the succession of life has followed a grand law of progress, involving under a single system a closer and closer approximation in the species, as time moved on, to those which now exist. It follows, therefore, that

Identity of species of fossils proves approximate identity of age.

Fossils are the best means we have for ascertaining the equivalency of strata, or their identity of age. Equivalency is sometimes shown in an identity of species; more often in a parallel series of nearly related species; often by an identity or close relation in the genera or families; often also in some prominent peculiarity of the various species under a family or class.

The progress in life has not consisted in change of species alone The species of a genus often present, in successive periods, some new feature; or the higher groups under an order or class some modification, or some new range of genera, so that, even when the species differ, the habit or general characters of the species, or the range of genera or families represented, may serve to determine the era to which a rock belongs, or at least to check off the eras to which it does not belong. Thus *Spirifer*, a genus of mollusks, which has a narrow form in the Silurian, has often a very broad form in the course of the Devonian and the Carboniferous ages. Ganoid fishes, which have vertebrated tails through long ages, have their tails not vertebrated in

after time. Trilobites become wholly extinct at a certain epoch in the history. And so in multitudes of cases.

This criterion based on fossils serves for the comparison of the continents with one another, as to their successions of rocks. Had we a table containing a list of the complete series of rocks, and of the families, genera, and species of fossils which each contains, it would be a key for use over the whole world, — South and North America as well as the Orient; and, by comparing the fossils of any rock under investigation with this key, the age would be approximately ascertained. This is the method now pursued in studying the geology of the globe. The key, is, in fact, already sufficiently complete to be constantly appealed to by the geological observer. The list which is made for the Silurian and Devonian rocks in New York State is used for identifying the strata of the Mississippi basin; and that which has been prepared in Europe is constantly employed to make out the equivalency of the rocks of the two continents.

By such comparison of fossils, it was discovered that the Chalk formation exists in the Atlantic border of the United States, although the region contains no *chalk*; that the coal formation of North America and that of Newcastle, England, belong in all probability to the same geological age; and so on.

The commencement in the preparation of such a key was attended with much difficulty. In New York State, it was necessary — first to study all the sections in the eastern, central, and western parts, and determine carefully the fossils in each stratum; then to compare the sections with one another: when any case of identity in the fossils among these strata of the different sections was observed, it was set down as one horizon determined. By this method, and other aid from observing the continuity of beds, one horizon after another was ascertained, and the strata between were arranged according to their true order of succession.

By the means explained, great progress has been made in arranging the rocks of the different continents in a chronological series. North America has some large blanks in the series, which in Europe are filled; and in this way various countries are contributing to its perfection.

But this criterion requires precaution in its applications, for the following reasons: —

1. *The difference in species attending difference of conditions in climate, soil, etc.* In the same regions, during any era, the species of the land differ from those of the waters: those of fresh water, from those of salt; those of the surface or *shallow waters*, from those of deeper, and in these *deeper waters* according to the depth; those of warm

waters, from those of cold, whether at the surface or in the deep ocean where oceanic currents make differences of temperature; those of warm or dry lands, from those of cold or *wet*; those of clear open seas, from those of muddy waters or near muddy seashores; those of rocky bottoms, from those of muddy; etc. Hence, an ancient rock made in a clear sea, as a limestone, will necessarily contain very different fossils from a rock that was made of mud, although they were formed at the very same time, in the same waters, and within a hundred miles of one another. Even a hundred yards may be all that separates widely different groups of species. Again, a rock made in fresh waters will differ in its fossils still more widely from that made synchronously in salt waters; a rock made in shallow waters, from one made at great depths; a rock made in the tropics, from one made in the temperate zone or the arctic, provided the zones at the time of the making differed as they do now in climate. Hence, *a very considerable difference in the fossils of rocks is consistent with their being contemporaneous in origin.*

2. *The difference in the time at which species or groups of species of different regions have become extinct.* In one region, changes may cause species or genera (or higher groups) to disappear, while, in another, subjected to the same conditions or causes of catastrophe, the same species, or at least the same genera (or higher groups), may continue on through another period. Genera or Families may become extinct sooner on one continent, or part of a continent, than on another; or in one ocean, or part of an ocean, than in another.

Catastrophes may affect the borders of an ocean or shallow seas, that do not reach the greater depths. Fossils of the group called Cystids occur only in the older rocks of the globe, and were supposed to have become extinct at the time of their disappearance as fossils; but recently they have been found in the depths of the Atlantic ocean, a region not reached by the agencies of extermination that swept from time to time over the continental seas. It was formerly supposed that no species that is now alive existed anterior to the Tertiary; but, in the same deep ocean, one living mollusk has been found that is supposed to date back to the Cretaceous or chalk era.

3. *The difference in the time at which species or groups have begun to exist in different regions.* The several continents may not have been exactly parallel, in all the steps of progress in the life of the globe, certain families commencing a little earlier in one than in another. Again, one continental sea or region may have received some of its species by migration from another, long after their first appearance. Here is a source of doubt, due on one side to special con-

tinental idiosyncrasies, and on the other to migrational distribution, which is always to be carefully considered.

Such facts do not lead to any doubt as to conclusions based on the *general range* of types characterizing an era. Should a trilobite be hereafter discovered in any Cretaceous rocks of the world, it would lead no one to suspect those rocks to be Paleozoic; because the associated species would unquestionably be true Cretaceous fossils.

2. UNSTRATIFIED CONDITION.

The larger part of the crystallized rocks were once fragmental rocks, and have been altered, that is, are *metamorphic* rocks (p. 66); and they are, therefore, not true examples of unstratified rocks. In general, they still retain the lines of deposition distinct. When gneiss and mica schist are found in alternations with one another, it is plain that each layer corresponds to a separate layer in the original deposit; and the beds, although crystalline, are still as really stratified as they ever were.

In some metamorphic rocks, however, the appearance of stratification is lost; and such may be properly said to be unstratified. Yet it should be understood that the name does not imply that they never were stratified, but that this is not now their apparent condition. Granite and syenyte are unstratified rocks of this kind. In much granite there is no lamination, no arrangement of the constituent minerals in parallel planes, no evidence of subdivision into layers. But even this true granite, a few miles off, may become gneiss in which a schistose structure is very distinct.

Examples of the unstratified condition are common among true igneous rocks. The ridges of trap or doleryte which range over many districts — as the Palisades on the Hudson, Mounts Tom and Holyoke and the other trap ridges of the Connecticut valley, the Giant's Causeway and Fingal's Cave — are some of these examples. The rocks were melted when they came up to the light through fissures; and they now stand without any marks of stratification. The sketch on p. 108 represents a scene among rocks of this kind in Australia. The dome-shaped masses of trachyte, in some regions of ancient volcanoes, and the interior mass of many great volcanoes, — sometimes exposed to view through rendings of the mountain or denudation by water, — are also examples. But the ordinary outflows of liquid rock from volcanoes usually produce layers, which are covered afterward by others in succession; and volcanic mountains, therefore, have to a great extent a stratified arrangement of the rock-material, and not less perfectly so than bluffs of stratified limestone. Moreover, the same rock

which forms the Giants' Causeway may in other places be interstratified among sandstones and shales; for the layer of igneous outflow,

Fig. 115.

Basaltic columns, coast of Illawarra, New South Wales.

wherever it takes place, may be followed afterward by deposits of sand or other sediment.

Another example of unstratified material is found in the loose pebbles and stones which cover a large part of the northern half of both the American and European continents. Any ordinary mode of action by water lays down sediments in layers. But these accumulations — often called *Drift* — are of vast extent and without layers. Wherever the same kind of material is in layers, it is then said to be stratified; and thus it is distinguished from the *unstratified.*

There may, therefore, be both stratified and unstratified fragmental, and stratified and unstratified igneous rocks; and, from the obliteration of the planes of deposition by metamorphism, there may be unstratified metamorphic rocks, like granite, as well as stratified.

On the subject of the structure of these rocks, it is only necessary to refer to the ordinary massive structure of granyte and trachyte, etc., and to the columnar structure met with among igneous rocks. The last is represented in the figure given above. There are all shades of perfection in this columnar structure, from prisms of great height with perfectly plane sides, to a mere tendency to prismatic forms; and also from this less perfect prismatic character, to the massive structure with no trace of columnar fracture.

For a continuation of this subject, see the chapter on igneous operations, under Dynamical Geology.

(1.) **General nature of veins.** — *The vein condition.* — Veins are narrow plates of rock intersecting other rocks. They are the fillings of cracks or fissures; and, as these cracks or fissures may either extend through the earth's crust and divide it for long distances, or

reach down only to a limited depth, or be confined to single strata, so veins are exceedingly various in extent. They may be no thicker than paper, or they may be scores of rods in width, like the great fissures opened at times to the earth's inner regions by subterranean agency. They may be clustered so as to make a perfect net-work through a rock, or may be few and distant. And, as strata have been faulted, so veins also may have their faults or displacements. All those subterranean movements that produce joints and fractures in rocks may give origin and peculiarities to veins.

(2.) **Subdivisions.** — Veins are divided into *dikes* and proper *veins.* Dikes are filled by volcanic rocks, basalt, trap, or some other igneous rock, and have regular and well-defined walls.

Veins are occupied by quartz, granitic rocks, metallic ores, calcite, fluor spar, barite, etc., — material which is less obviously a liquid injection from below, and probably is seldom of this nature. They are generally irregular in form, often indistinct in their walls, and very varying in their ingredients. They abound in regions of meta-

Fig. 116.

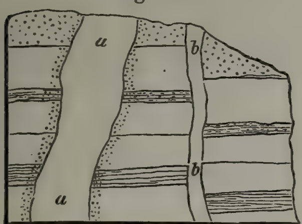
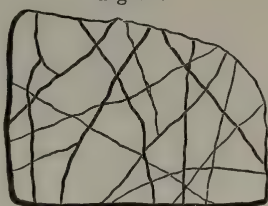


Fig. 117.



morphic rocks. Veins have been subdivided into kinds; but the divisions need not here be considered.

(3.) **Forms and faults of veins and dikes.** — Fig. 116 represents two simple veins or dikes (*a a* and *b b*) intersecting stratified rocks.

Fig. 117, a net-work of small veins.

Fig. 118.

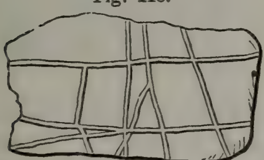


Fig. 119.

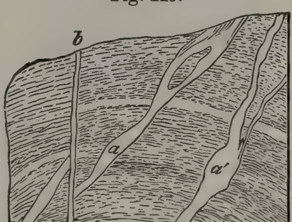
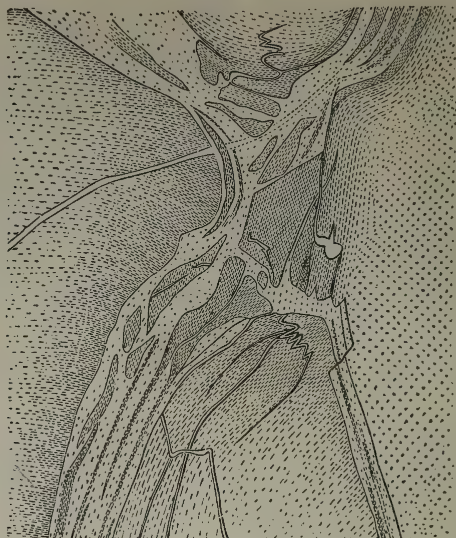


Fig. 118, small veins of quartz intersecting gneiss, — the mass five feet square. The veins do not all cross one another, and correspond to the cracks which result from contraction, as by sun-drying or cooling, rather than to those of any other mode of fissuring.

Fig. 119. Two veins *a a′*, presenting some of the common irregularities of mineral veins in size, the enlarged parts containing mostly the ore: *a* is faulted by another vein *b*, which is therefore of subsequent formation, but not necessarily long subsequent.

Fig. 120.



Figs. 120, 121, 122. Examples of granitic veins of very large size, in a gneissoid granite, showing their subdivisions and various irregularities (taken by the author

Fig. 121.

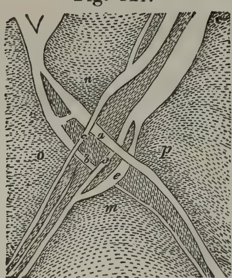
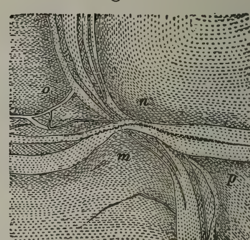


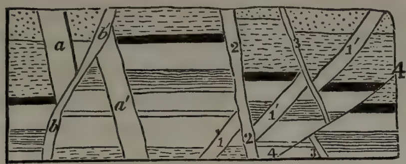
Fig. 122.



from granitic rocks near Valparaiso). The veins undergo constant changes of size, and in some places encircle masses of rock resembling the rock outside The rock adjoining the vein is more micaceous than that at a distance, and the direction of the lamination (as indicated in the figures) varies with some reference to the intersecting veins, curving approximately parallel to the veins on two opposite sides, *m* and *n*, and not at all so on the other two, *o* and *p*. The subdivisions of the veins in Fig. 121 cross one another in an alternate manner, *a* cutting *d* and *e*, but cut by *c*, and *b* cut by *c*, *d*, and *e*; in 122, although the veins are similar in constitution, one cuts the other; and, in 120, the two crossing veins are broken and subdivided at the intersection, so as to appear like one vein stretching off in two directions, like a letter X.

Fig. 123. A vein *a* faulted by *b*, — whence it is inferred that *b* is subsequent to *a* in age. Also a vein 1 faulted by 2, and again by 3, and 3 faulted by 4; 2 and 3,

Fig. 123.



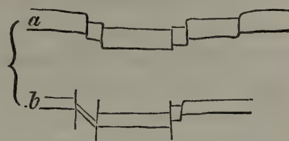
therefore, were subsequent in age to 1, and 4 was subsequent to 3. The faulting is exhibited also in the layers of the stratified rocks which the veins intersect.

Fig. 124.

Fig. 125.

Fig. 126.

Fig. 127.



Figs. 124, 125, 126. Veins much broken or faulted: in 124, four faults within a length of eighteen inches: in 125, six faults in six feet; in 126, the broken parts of the vein of unequal breadth.

Fig. 128.

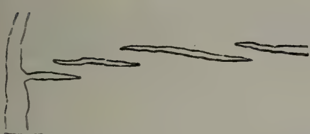
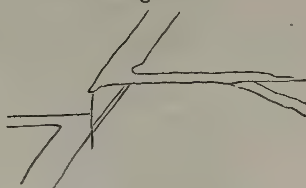


Fig. 129.



Figs. 127, 128, 129. Other faulted veins: 127 *a* and *b*, six feet apart, and still different in their faults; 128, 129, other interrupted veins. These dissimilarities between the parts of one faulted vein, as in 126, and between the parts of two parallel veins, as in 127, arise from an oblique shove of the parts, either at the time of the fracturing in which the veins themselves originated, or at some subsequent fracturing.

The points illustrated in the preceding figures are, —

The great irregularities of size in veins along their courses, swelling out and contracting; their occasional reticulations; their frequently embracing portions of the enclosed rock; their numerous faultings, or breaks and displacements.

(4.) **Structure.** — *Dikes.* — Dikes consist essentially of the same kind of material from side to side and at all heights, where not

altered by exposure to the air. The structure may be simply massive, or cracked irregularly, as in many volcanic dikes. But frequently there are transverse fractures, producing a columnar structure, so that a dike is like a pile of columns. For a short distance from the walls, the structure is generally imperfect (Fig. 130); and in many cases there is an earthy layer along the sides, or even a laminated structure parallel with the walls (Fig. 131), produced by the friction of the rising liquid mass against the walls of the fissure.

Fig. 130.

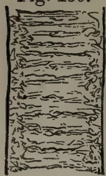
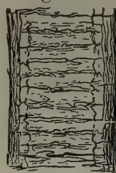


Fig. 131.



Dikes are sometimes metalliferous; and, when so, the ore is commonly found near the walls, and often penetrates also the enclosing rock. Some of the richest mines of the world are connected with dikes, or with igneous ejections.

Veins never have the transverse columnar structure of dikes. The simplest consist of one kind of material, — as quartz, granite, heavy spar, — and are alike from side to side. But others have a banded structure not found in dikes, consisting in an arrangement of the material parallel to the walls. Fig. 132 represents such a vein consisting of ten bands: 1, 3, and 6 are bands of quartz; 2 and 4, of a gneissoid granyte; and 5, of gneiss. Of banded veins, the simplest is a vein with three bands, one central; but the number may be a score or more. The bands may be partly metallic ores of different kinds, and calcite, barite, fluor spar, may make the alternating bands,

Fig. 132.

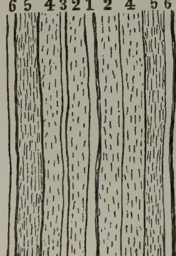
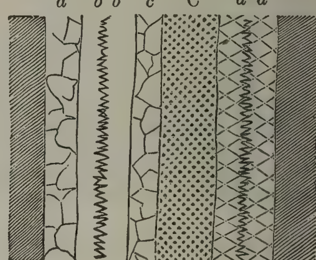


Fig 133.



instead of granite or gneiss. In Fig. 133, there are three sets of bands: an inner, C, and two outer. The left-hand one consists of four bands or combs, *a*, *b*, *b*, *c* of earthy minerals, with ore along the centre; and that to the right of two combs, *a*, *a*, with a central line of ore; while C is a simple band, and it may be of ore. A great

vein at Freiberg consists of layers of blende, quartz, fluor spar, pyrite, heavy spar, calcite, each two or three times repeated, the layers nearly corresponding on either side of the middle seam.

The bands of a vein are far from uniform at different heights, even when the width of the vein is constant; and they vary exceedingly through the contractions and expansions which take place at intervals. The expanded portions may alone be banded, or consist of layers parallel to the sides, or contain ore.

The mineral or rock-material accompanying the ore in a vein is called the *vein-stone*, or *gangue*. The most common kinds of vein-stone are quartz, calcite, barite, and fluorite.

In studying veins, besides noting their extent, mineral character and structure, it is important to ascertain their strike and angle of dip. There is generally an approximate uniformity of strike in a given region; and frequently the direction is parallel to the principal line of elevation in the region. The nature of the walls or adjoining rock, and systems of faults, are other points that should receive close attention.

False veins. — False veins are fissures filled from above. They are usually distinguished by the sedimentary nature of the material; all true dikes or veins are occupied by crystalline rocks or minerals. In a similar manner, earth and organic remains may be washed into caverns or any open spaces in rocks, and so make, in the very body of an old record, a false entry.

Such openings may become filled, from above, either with sand or rock, or with metallic ores. The lead ore of Wisconsin, Galena in Northern Illinois, and Missouri, occupies, according to J. D. Whitney, great irregular cavities in the rock of the region, a limestone, and is not in true veins. The same is the case with the lead ore of Derbyshire and Cumberland, England: for, along with the ore, and especially near the limestone walls of the cavities, or so-called veins, there are sometimes many fossils, partly those of the enclosing limestone, but many those of later rocks, showing not only that the filling in of the ore was from above, but also that it was much subsequent in time to the origin of the limestone (p. 104).

Again, some of the *so-called veins* of metallic or mineral material are only *beds*. They have the aspect of veins, because the rocks have been upturned so as to make the beds vertical, or nearly so, in position. The great "veins" of iron ore in northern New York, and the Marquette region, Michigan, and of zinc-iron ore (franklinite) in New Jersey, are examples. The rocks of the region are all metamorphic, and *so is the iron ore*, which originally was a layer of uncrystalline ore much like those of the Coal formation in Pennsylvania. Many of the metallic "veins" of the world, even those of zinc, copper, cobalt, etc., are properly metalliferous layers, somewhat disguised by upturning and metamorphism. So also crystalline limestone, in northern New York and Canada, sometimes *appears* to be in veins, and has been so described, when, in fact, it is strictly in layers, and is one of the metamorphic stratified rocks of the region.

In the language of miners, —

A *lode* is a vein containing ore.

The *hanging wall* of a vein is the upper wall when the vein has an oblique dip; and the opposite is the *foot-wall.*

The *fluccan* is the half-decomposed rock adjoining a vein.

A *horse* is a body of rock, like the wall-rock in kind, occurring in the course of a vein.

A *comb* is one of the layers in a banded vein, — so called especially when its surface is more or less set with crystals. A cavity in a vein set around with crystals is called a *geode*.

Country, *country-rock*, *wall-rock* are terms applied to the rock in which a lode occurs.

A *reef*, in Australian gold mining, is a large auriferous quartz vein.

Selvage is a thin band of earthy matter between a lode and its walls, or the sharp line of demarcation between a lode and the wall-rock.

A *branch* or *leader* is a small vein striking out from the main lode.

Fahlbands, in Germany, Norway, etc., are metalliferous belts or zones; they sometimes consist of *ore-bands* (Erzbänder), and rock-bands (Felsbänder); or the lodes of the region may be rich in ore only where they intersect the Fahlbands.

On metallic veins, see further, WHITNEY'S "Metallic Wealth of the United States" (Philad. 1854), and COTTA'S excellent "Treatise on Ore Deposits" (New York, 1869).

The progress of the life of the globe is one of the two great subjects that come before the student, in the following part of this Manual, treating of HISTORICAL GEOLOGY. By way of introduction to it, a short chapter on its system of structures is here introduced.

BRIEF REVIEW OF THE SYSTEM OF LIFE.

1. GENERAL CONSIDERATIONS.

1. *Life.* — Some of the distinctions between a living organism and inorganic or mineral substances have been mentioned. Recapitulating them, with additions, they are: —

(1.) The *living being* has, as the *fundamental element* of its structures, visible cells, containing fluids or plastic material; instead of invisible molecules.

(2.) It *enlarges* by means of imbibed nutriment, through a process of evolution; and not by mere accretion or crystallization.

(3.) It has the faculty of converting the nutriment received, into the various chemical compounds essential to its constitution, and of continuing this process of assimilation as long as the functions of life continue; and it loses this chemical power when life ceases.

(4.) It passes through successive stages in structure, and in chemistry, from the simple germ to a more or less complex adult state, and finally evolves other germs for the continuance of the species; instead of being equally perfect and equally simple in all its stages, and essentially germless.

There is, therefore, in the living organism, something besides mere

physical forces, or the chemistry of dead nature — something that ceases to be when life ceases. There is a *vital condition*, in which molecules have powers that lead to resulting seed-bearing structures, widely different from those of inorganic nature, and standing on altogether a higher level. There is a power of evolution, an architectonic power, that not only exalts chemical results, but evolves a diversity of parts and structures, and a heritage of ancestral qualities, of which the laws of material nature give no explanation.

2. *Vegetable and Animal Life.* — The vegetable and animal kingdoms are the *opposite*, but mutually dependent, sides or parts of one system of life. The following are some of their distinctive characteristics: —

(1.) Plants take nutriment into the tissues by absorption, and assimilate it without the aid of a stomach, or any digestive fluid; animals have a mouth, and receive food into a sac or stomach. Exceptions to this feature of animal life occur only in the lowest microscopic forms and certain parasitic kinds; and the most of these extemporize a mouth and stomach whenever any particle of food comes in contact with the outer surface, so that even here the food is digested in an interior cavity.

(2.) Plants find nutriment in carbonic acid, appropriate the carbon, and excrete oxygen, a gas essential to animal life; animals use oxygen in respiration, and excrete carbonic acid, a gas essential to vegetable life.

(3.) Plants take inorganic material as food, and turn it into organic; animals take this organic material thus prepared (plants), or other organic materials made from it (animals), finding no nutriment in inorganic matter.

(4.) The Vegetable kingdom is a provision for the storing away or magazining of force for the Animal kingdom. This force is acquired through the sun's influence or forces acting on the plant, and so promoting growth; mineral matter is thereby carried up to a higher grade of composition, that of starch, gluten, and vegetable fibre, and this is a state of concentrated or accumulated force. To this stored force animals go in order to carry forward their development; and, moreover, the grade of composition thus rises still higher, to muscle and nerve (which contain much nitrogen in addition to the ordinary constituents of the plant); and this is a magazining of force in a still more concentrated or condensed state.

(5.) Plants of some minute kinds, and the spores of some larger species (some Algæ), have locomotion, or a degree of contractility in certain parts that corresponds to an infinitesimal amount of mechanical power; but the locomotive spores, as they develop, become fixed, like

the plants from ordinary seeds, and no increase of mechanical power ever accompanies vegetable development. In animal development from the germ, on the contrary, there is always an increase of power — an increase, in all, of muscular power, and, in the case of species above the lower grade, of psychical and intellectual power, — until an ant, for example, becomes a one-ant power, a horse a one-horse power. Whence, an animal is a self-propagating piece of enginery, of various power according to the species.

(6.) In the plant, the root grows downward (or *dark*-ward) and the stem upward (or *light*-ward), and there is thus the *up-and-down* polarity of growth — the higher developments, those connected with the fruit, taking place above, or in the light. In the animal, there is an *antero-posterior* polarity of power as well as growth — the head, which is the seat of the chief nervous mass and of the senses, and the locus of the mouth, making the anterior extremity. Consequently, there is in animals a connection between grade and the greater or less dominance and perfection of the head extremity. An animal, as its ordinary movements manifest, is preëminently a *go-ahead* thing. Even the inferior stationary species, like the polyp, show it in the superior power that belongs to the mouth extremity.

(7.) Plants have no consciousness of self, or of other existences; animals are conscious of an outer world, and even the lowest show it by avoiding obstacles.

From the above diverse characteristics of plants and animals, it follows that, however alike the germs of the two are chemically (that is, although containing the same elements in the same proportions), they must be in their chemical nature fundamentally different.

2. ANIMAL KINGDOM.

In the Animal Kingdom, there are *five* SUB-KINGDOMS, based on distinct types of structure, each having its system of subdivisions of several grades or ranks. These sub-kingdoms are as follow, beginning with the lowest: —

I. PROTOZOANS; II. RADIATES; III. MOLLUSKS; IV. ARTICULATES; V. VERTEBRATES.

The Animal Kingdom may also be divided into INVERTEBRATES, and VERTEBRATES — Radiates, Mollusks, Articulates, and Protozoans being the Invertebrates.

I. Protozoans, the lowest and simplest of animals, show their simplicity in their minuteness (mostly between a 100th and a 10,000th of an inch in length); in having no external organs except a mouth and minute cilia or thread-like processes, and no digestive apparatus beyond a stomach; in the fact that the stomach and mouth are some-

times wanting, or exist only when extemporized for the occasion; in having no heart or circulating system, beyond a palpitating vesicle or vacuole. Many of the Infusorians or Animalcules are here included.

II. **Radiates.** — Having a *radiate* structure, like a flower, internally as well as externally; that is, having similar parts or organs repeated around a vertical axis. The animals have a mouth and stomach for eating and digestion, and hence they are widely diverse from plants, although resembling them in their radiate arrangement of parts.

Figs. 137 to 149 represent examples of Radiates: 137, an *Actinia*, or *Polyp*; 138, 139, living corals, the animals of which are polyps; 140, a *Medusa* or *Acaleph*, — also called *Jelly-fish*, — showing well the internal as well as external radiate structure, as the animal is nearly transparent; 141, 142, polyp-like species of the class of Acalephs; 143, an *Echinus*, or *Sea urchin*, — but not perfect, as the spines which cover the shell and give origin to the name *Echinus* are removed from half its surface, to show the shell; 144, a *Star-fish*; 145, 146, *Crinoids*, — animals like an inverted Star-fish or Echinus, stand-

Figs. 137–146.

RADIATES, Figs. 137–146. 1. *Polyps:* Fig. 137, an Actinia; 138, a coral, Dendrophyllia; 139, a coral of the genus Gorgonia. 2. *Acalephs:* 140, a Medusa, genus Tiaropsis; 141, Hydra (× 8); 142, Syncoryna. 3. *Echinoderms:* 143, Echinus, the spines removed from half the surface. (× ⅓); 144, Star-fish, Palæaster Niagarensis; 145, *Crinoid*, Encrinus liliiformis; 146, *Crinoid*, of the family of Cystids, Callocystites Jewettii.

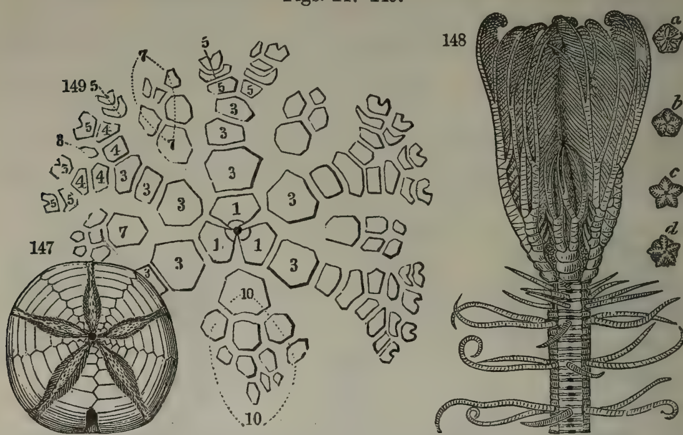
ing on a stem or pedicel, like a flower. Fig. 147, on the next page, is the shell of another Sea-urchin; and Fig. 148, another Crinoid. Figs. 573 to 582 are additional examples of Radiates.

The radiate feature exists not only in the external form, but also in the interior structure. The mouth, when furnished with calcareous

jaws or mandibles, has a circle of five of them; and the nervous system, when distinct, is circular in arrangement.

III. Mollusks. — The structure, essentially: (1) a soft fleshy bag, containing the stomach and viscera, (2) without a radiate structure, and (3) without articulations or jointed appendages. The animals of the *Oyster* and *Snail* are examples. *Similar parts are repeated on the right and left sides of a median plane,* as in Articulates and Vertebrates, and not around a vertical axis, as in Radiates. They are essentially simple in fundamental structure, and not multiplicate in successive parts, like an Articulate.

Figs. 147–149.



RADIATES. — Fig. 147, an Echinus without its spines, — the Clypeus Hugi of the Oölyte; 148, the living Pentacrinus Caput-Medusæ of the West Indies (× ½); *a*, *b*, *c*, *d*, outlines of the stems of different species of Pentacrini; 149, plates composing the body of the Crinid, Batocrinus longirostris (wrongly reversed in copying from Hall).

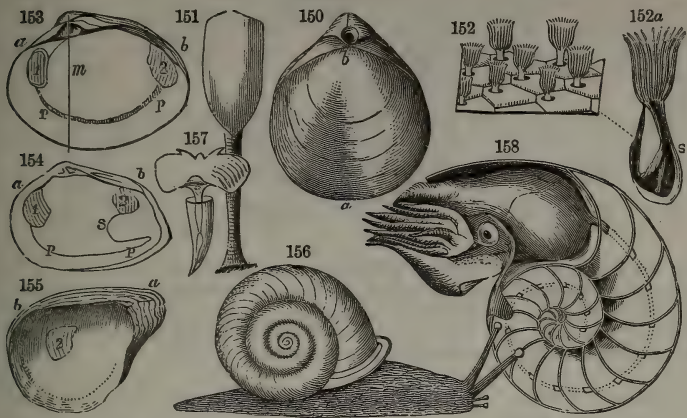
Figs. 150 to 159 represent some of the kinds of Mollusks. Figs. 150, 153, 154, 155, are shells of different species; 156, the shell of a Snail, with its animal; 158, another shell, the *Nautilus*, with its animal; 152, a magnified view of a minute coral, with the living animals projecting from the cells, which, although apparently radiated like a polyp, are still Mollusks, because this radiation is only external, as is apparent in Fig. 152 *a*, which represents one of the animals taken out of the cell and more magnified. Fig. 159, on the next page, is another Mollusk, — a Cephalopod, — having some resemblance to a Radiate in the position of the arms, but none beyond this. The name Mollusk is from the Latin *mollis, soft.* The shells are for the protection of the soft, fleshy bodies.

IV. Articulates. — Consisting (1) of a series of joints or segments; (2) having the legs, when any exist, jointed; (3) having the viscera

and nervous cord in the same general cavity; (4) having no *internal* skeleton; as *Worms*, *Crustaceans*, *Insects*.

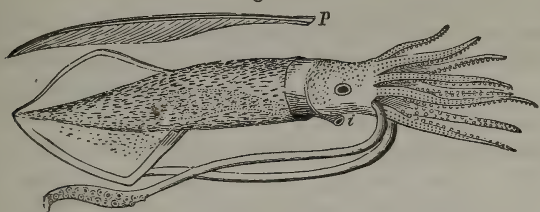
The articulations are made in the hardened skin, and not, as in Vertebrates, in internal bones; and the principal nervous cord passes

Figs. 150–158.



MOLLUSKS, Figs. 150–158. — 1. *Brachiopods:* 150, Terebratula impressa, of the Oölyte; 151, Lingula, on its stem. 2. *Bryozoa:* 152 ($\times 8$), 152 *a*, genus Eschara. 3. *Lamellibranchs* (*Common Bivalves*): 153, 154; 155, the Oyster. 4. *Gasteropods:* 156, Helix. 5. *Pteropods:* 157, genus Cleodora. 6. *Cephalopods:* 158, Nautilus ($\times \frac{1}{6}$).

Fig. 159.



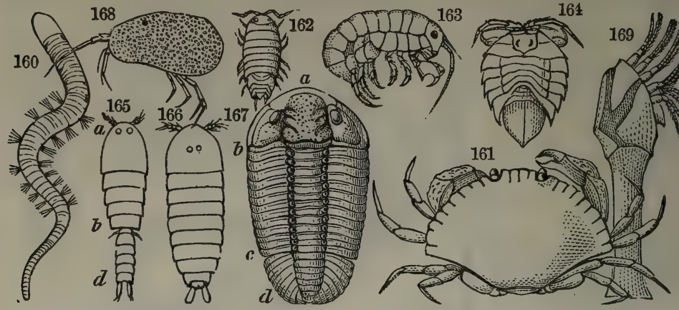
The Calamary or Squid, Loligo vulgaris (length of body, 6 to 12 inches); *i*, the duct by which the ink is thrown out; *p*, the "pen."

below the stomach and intestine, and has usually a ganglion for each segment of the body, — so that the *articulate* structure is indicated by the nervous system, as well as by the joints of the body and its members. The fundamental element of the body is, hence, a segment or ring containing a nervous ganglion and a portion of the viscera. An Articulate is thus multiplicate in structure, or consists of successive approximately similar segments or parts, and is thus unlike the Mollusks.

Some of the Articulates are shown in Figs. 160 to 169. Fig. 160 is a sea-shore worm; 161, a Crab; 162 to 167, other Crustaceans;

168, another Crustacean, having a shell like a Mollusk, but showing that it is a true Articulate by its *jointed* legs and antennæ, and its

Figs. 160–169.



ARTICULATES, Figs. 160–169. — 1. *Worms:* 160, Arenicola marina, or Lob-worm (×1/6). 2. *Crustaceans*: 161, Crab, species of Cancer; 162, an Isopod, species of Porcellio; 163, an Amphipod, species of Orchestia; 164, an Isopod, species of Serolis (×½); 165, 166, Sapphirina Iris; 165, female, 166, male (×6); 167, Trilobite, Calymene Blumenbachii; 168, Cythere Americana, of the Cypris family (×12); 169, Anatifa, of the Cirriped tribe.

jointed body within the shell; 169, representing a Cirriped, is also somewhat like a Mollusk in its shell, — though articulate in structure, as the legs show, and, in fact, a Crustacean. Centipedes, and all Insects, as well as Worms, are other examples of Articulates, the body consisting of a number of segments. The name of the sub-kingdom is from *articulus, a joint.*

V. Vertebrates. — Having (1) a jointed internal skeleton, and (2) a bone-sheathed cavity along the back, for the great nervous cord, distinct from the cavity for the viscera: as in *Fishes, Reptiles, Birds, Quadrupeds.*

The skeleton is made up of vertebræ, or the bones of the vertebral column, with their appendages; and a vertebra is the fundamental element of the structure. The bone-sheathed cavity occupied by the nervous cord is enclosed by processes from the upper (or dorsal) side of the vertebræ, and the visceral cavity by the ribs, which are processes from the lower side of the vertebræ. The legs and arms are appendages to the system of vertebræ and ribs.

Recapitulation. — In Radiates, the structure is radiate or flower-like. In Mollusks, it is bag-like and simple. In Articulates, it is made of a series of rings, and is composite in the structure of both the skeleton and the nervous system. In Vertebrates, it contains a series of vertebræ, and is composite in the skeleton; and, besides, it has separate cavities for the nervous cord and viscera.

SUBDIVISIONS OF THE SUBKINGDOMS.

I. Vertebrates.

The five classes are: —

1. Mammals. — Species suckling their young, — a characteristic peculiar to this highest branch of the animal kingdom; breathing by lungs; having a heart of four cavities: as ordinary Quadrupeds, with Whales and Seals.

2. Birds. — Oviparous; breathing by lungs; heart of four cavities; covered with feathers, and adapted for flying.

3. Reptiles. — Oviparous; breathing by lungs; a heart of three or four cavities; naked or covered with scales: as Crocodiles, Lizards, Turtles, Snakes.

4. Amphibians. — Oviparous; breathing when young by gills, and afterward by lungs alone; a heart of three cavities; naked or covered by scales: as Frogs and Salamanders.

5. Fishes. — Usually oviparous; heart usually of two cavities; breathing by gills; naked, or covered with scales.

II. Articulates.

The Articulates include (1) the *Arthropods* (so named from *αρθρον joint*, and *πους foot*), or those having jointed legs; and (2) *Worms* (or Annelids), those without them.

I. Arthropods. The Arthropods are divided into two groups based on adaptation to life in the air or in the water; and, further, into classes according to structure.

A. The *Terrestrial*, which have lung-like cavities, or breathing-holes (spiracles), and a system inside for air-circulation. In this division there are —

1. *Insects.* — Having the body in three parts, that is, a distinct head, thorax, and abdomen; and only three pairs of legs: as, Beetles, Flies, Butterflies.

2. *Spiders.* — Having the body in two parts, or, in the lowest, only one, the head and thorax not separate segments.

3. *Myriapods.* — Having a worm-like form, and numerous pairs of legs.

B. The *Aquatic*, which have gills for aquatic respiration, or else some other part of the body serving this purpose. Here belong —

Crustaceans. — The body in two parts, — the anterior called the *cephalothorax*, consisting of a head and thorax, the posterior called the *abdomen:* as, Crabs, Lobsters, Shrimps.

II. Worms. — Worm-like in form, consisting of many segments, without any division into cephalo-thorax and abdomen; the body fleshy; no jointed legs, though often furnished with tubercles, lamellæ, or bristles. *Examples:* the Earth-worm, Leech, Serpula.

The aquatic species of Articulates commence in the Silurian, and are here further explained.

Crustaceans. — Among Crustaceans, there are three orders: —

The *first*, or highest, *ten-footed* species, or *Decapods;* as Crabs (Fig. 161) and Lobsters.

The *second*, *fourteen-footed* species, or *Tetradecapods* (Figs. 162, 163, 164).

The *third* and lowest, irregular in number of feet, and unlike the Tetradecapods, also, in not having a series of appendages to the abdomen: the species are called *Entomostracans*, from the Greek for *insects with shells.*

(*a.*) Among the *Decapods*, Crabs are called *Brachyurans*, — from the Greek for *short-tailed*, the abdomen being small and folded up under the body; the Lobsters and Shrimps, *Macrurans*, — from the Greek for *long-tailed*, the abdomen being rarely shorter than the rest of the body.

(*b.*) Among the *Tetradecapods*, Figs. 162, 164 represent species of the tribe of *Isopods* (a word meaning equal-footed), and Fig. 163, of that of *Amphipods* (feet of two kinds, abdominal as well as thoracic). Fig. 162 is the Sow-bug, common under stones and dead logs in moist soil. Fig. 163 is the Sand-flea, abundant among the sea-weed thrown up on a coast. In Figs. 162, 164 (Isopods), the abdomen is abruptly narrower than the cephalothorax; its appendages underneath are gills. In Fig. 163 (Amphipod), the abdomen is the part of the body following (usually) the eighth segment; its appendages are swimming legs and stylets, —the gills in Amphipods being attached to the bases of the true legs, and not to the abdomen.

(*c*) Among *Entomostracans*, the forms are very various. The absence of a series of abdominal appendages is the most persistent characteristic. The eyes, in a few species, have a prominent cornea; but, in the most of them, the cornea is internal, and there is no projection. In the *Cyclops group*, the species have often a shrimp-like form, as in Fig. 165, though usually minute. Sometimes the male and female differ much in form: 166 is male, and 165 female of the *Sapphirina Iris; a b* is the cephalothorax, and *b d* the abdomen. There are legs on the under surface of the anterior part, fitted for grasping, and others, behind these, for swimming. In the *Cypris group*, the animal is contained in a bivalve shell, as in Fig. 168, and they are hence called *Ostracoids.* They are seldom a quarter of an inch long. In the *Limulus group*, — containing the Horseshoe of the sea-coasts of the United States, — there is a broad, shield-like shell, and a number of stout legs, the basal joints of which serve for jaws. In the *Phyllopod group*, the form is either shrimp-like, approaching *Cyclops*, or like *Daphnia* or *Cypris;* but the appendages or legs are foliaceous and excessively numerous: the name is from the Greek for leaf-like feet. In the *Cirriped* or *Barnacle group*, the animal has usually a hard, calcareous shell, and it is permanently attached to some support, as in the *Anatifa* (Fig. 169) and *Barnacle*. The animal opens a valve at the top of the shell, and throws out its several pairs of jointed arms looking a little like a curl, and thus takes its food, — whence the name, from the Latin *cirrus, a curl*, and *pes, foot.* The *Anatifa* has a fleshy stem, while the ordinary *Barnacle* is fixed firmly by the shell to its support.

Trilobites. — The *Trilobites* (Fig. 167, and also 251, and 360, 448,

pp. 175, 202, 227) existed only in Paleozoic time. They have jointed bodies with a crust-like exterior, and were aquatic, like all Crustaceans; and externally they resemble some Tetradecapods (Fig. 164). But they are most closely related to the modern species of Limulus (one of which is the large "Horse-shoe" of the Atlantic coast); yet, unlike the Limuli, their legs were very slender or wanting. The name *Trilobite* refers to the division of the body by two longitudinal depressions or sutures, into three parts (Fig. 267); but in some species, this character is indistinct.

The Limuli differ from other Crustaceans in interior structure and in embryological development; and they have hence been recently made into a separate group, which includes also, besides Trilobites, the *Eurypterids* (Fig. 474, page 239).

In the *Trilobite*, the shell of the head-portion (*a b*, Fig. 167) is usually called the *buckler;* the tail- (or properly abdominal) shield, when there is one (Fig. 360), the *pygidium.* The buckler (*a b*) is divided by a longitudinal depression into the *cheeks* or lateral areas, and the *glabella*, or middle area (Fig. 167). The cheeks are usually divided by a suture extending from the front margin by the inner side of the eye to either the posterior or the lateral margin of the shell. In Fig. 167 (*Calymene Blumenbachii*), this suture terminates near the posterior outer angle. The glabella may have a plane surface, or be more or less deeply transversely furrowed (Fig. 167), and usually with only three pairs of furrows.

Worms or Annelids. — The Annelids include, 1, the *Chætopods*, having setæ for locomotion; 2, the *Sipunculoids*, having the body smooth and cylindrical; 3, the *Bdelloids*, or Leeches; besides the two groups of free-swimming oceanic species, called *Chætognaths* (Sagittæ), and *Gymnocopa* (Tomopteris).

The Chætopods embrace the groups —

(1.) *Dorsibranchs*, or *free* sea worms, having in general short branchial appendages along the back. Many swim free in the open sea, and others live in the sands of sea-shores or the muddy bottom. The *Arenicola* family includes species that burrow in the sands of sea-shores. Fig. 160 represents the *A. marina*, or Lob-worm, which is common on European and American shores, and grows to the size of the finger. One species of *Eunice* has a length of four feet.

(2.) The *Tubicola*, or Serpula tribe, which live in a calcareous or membranous tube, and have a delicate branchial flower, often of great beauty, near the head. They are confined to salt water. The tubes often penetrate corals, and the branchial flower comes out as a rival of the coral polyps around it.

(3.) The *Terricola* (Oligochæta), or Earth-worm tribe, destitute of branchial appendages; as the common Earth-worm.

The *Helminths*, or *Intestinal worms*, are not here included among Articulates.

III. Mollusks.

The three grand divisions of Mollusks are —

I. Ordinary Mollusks, having usually regular gills or *branchiæ*, in addition to an outer enveloping fold of the skin called a *pallium*, from the Latin for *cloak;* as the *oyster*, *snail*, and *cuttle-fish.*

II. Ascidian Mollusks. Unlike *Ordinary Mollusks* in being

without regular branchiæ; and unlike the *Brachiate Mollusks* in not having a circle or spiral of ciliated tentacles, or having them only in a rudimentary state. Also having a leathery or membranous exterior, without a shell.

III. BRACHIATE MOLLUSKS. Without regular branchiæ; the shells, when any exist, bivalve, but transverse across the back and venter, instead of vertical either side of the body; the head having a fringe of slender organs arranged around the mouth, or in two spiral groups either side of the mouth. These Mollusks, the earliest in geological history, have some worm-like characteristics, as shown by Morse; but they are true Mollusks in wanting the multiplicate feature of Articulates, as well as in other points.

I. ORDINARY MOLLUSKS.

The ORDINARY Mollusks are divided into —

(1.) The *Acephals*, or *headless Mollusks*, the head not being distinctly defined in outline; as the *Oyster* and *Clam;*

(2.) The *Cephalates*, having a defined head; as the *Snail;* and,

(3.) The *Cephalopods*, having the head furnished with long arms (or feet); as the *Cuttle-fish.*

The Acephals have a mouth, but no perfect organs of sight; the Cephalates have distinct eyes and a distinct head (Fig. 156); the Cephalopods have the eyes large, and can grasp with great power by means of their arms, which are furnished with suckers (Fig. 159).

The pallium starts from the back, and often covers the sides of the body like a cloak, and is either open or closed along the venter: it is also called a *mantle.* It lies against the shell in the oyster, clam and allied species, and secretes it; and, in some univalves or Gasteropods, it may be extended out over more or less of the exterior of the shell.

1. **Cephalopods, or Cuttle-fishes.** — There are two orders of Cephalopods; one having external shells, and four gills or branchiæ; a second, having sometimes internal shells but no external, and having but two branchiæ. The external shells are distinguished from those of Gasteropods (or ordinary univalves) by having, with a rare exception, transverse partitions, — whence they are called *chambered* shells (Fig. 158). They may be either straight, or coiled; but with few exceptions they are coiled in a plane, instead of being spiral. A tube, called a *siphuncle*, passes through the partitions; and this siphuncle may either be central or nearly so, as in the genus *Nautilus* (Fig. 158, which represents a shell cut through the middle plane, so as to show the partitions and the siphuncle), or lie along the inner or *ventral* side of the cavity, or the outer or *dorsal* side, as in *Ammonites.*

The animal occupies the outer chamber, as in Fig. 158. These chambered shells containing Cephalopods were once extremely numerous; but less than half a dozen living species are known, and these are of the genus *Nautilus.*

Modern Cephalopods are almost exclusively *naked* species, having an *internal* shell, if any. In a few species, as in the genus *Spirula,* the internal shell is chambered and coiled (the coils not touching); but in the rest it is straight, lying in the mantle along the back, and serves only to stiffen the soft body. In the Cuttle-fish it is spongy-calcareous. In the Squid, or Calamary, — a more slender animal, requiring some flexibility for its movements, — it is horny, and is called the pen (*p*, Fig. 159 p. 119). In some cases, it has a small conical cavity at the lower end. In the Belemnites, a group of fossil species, it was stout, cylindrical and calcareous, with a deep conical cavity, and on one side the margin was prolonged into a thin blade (Figs. 792, 793).

The mouth of the Cephalopods has often a pair of horny mandibles, like the beak of a hawk in form; and these beaks, when fossilized, have been called *Rhyncholites.*

2. **Cephalates.** — The Cephalates are divided into two groups: —

(1.) The *Gasteropods*, the group containing the *Univalve* shells, as well as some related species without shells, — the animals of which crawl on a flat spreading fleshy organ called the *foot* (Fig. 156); and hence the name, from the Greek, implying that they use the *venter* (γαστήρ in Greek), or under surface, for a foot.

(2.) The *Pteropods*, which swim by means of wing-like appendages (Fig. 157), — to which the name refers, meaning *wing-footed* (from πτερόν, *wing*, and πούς, *foot*).

The Gasteropods, which embrace nearly all the cephalate Mollusks, have usually a spiral shell, as in the common Snail, Buccinum, Turbo, etc. The mantle of the animal is sometimes prolonged into a tube or siphon, to convey water to the gills; and, in this case, the shell often has a *canal* at the beak for the passage of the siphon. The modern marine univalves without a beak, the Natica group and some others excepted, are herbivorous, while those having a beak are as generally carnivorous.

3. **Acephals, or Headless Mollusks.** — There is but one group, the *Lamellibranchs.* — These common species are well known as *bivalves.* Between the mantle or pallium and the body of the animal lie the lamellar branchiæ, or gills, as is obvious in an oyster; and hence the name *Lamellibranchs.* In a shell like Fig. 153, p. 119, the mouth of the animal faces almost always (except in some species of *Nucula* and *Solemya*) the margin *a*, or the side of the *shorter* slope; and *a* is therefore the *anterior* side, *b* the *posterior;* and, placing the animal with the short slope in front, one valve is the *right* and the other the *left.* The hinge is at the back of the Mollusk.

On the lower margin of the animal, toward the front part, there is, in the Clam and most other species, a tough portion which is called the *foot:* it is used, when large, for locomotion, as in the fresh-water Clam; when small, it sometimes gives origin to the byssus by which shells like the Mussel are attached. It is wanting, or nearly so, in the Oyster.

The mantle is sometimes free at the lower margin, as in the Oyster; sometimes the edges of the two sides are united, making a cavity about the body, open at the ends; in other cases, this cavity is prolonged into a tube or siphon, or into two tubes projecting behind, one receiving water for the gills, and the other giving the water exit. The shell is closed by one muscle in the Oyster, etc., by two in the Clam, etc. The species with two muscles are called *Dimyaries,* — from the Greek for *two muscles;* and those with one, *Monomyaries,* — from the Greek for *one muscle.*

These different peculiarities of the animal are partly marked on the shell. In Figs. 153, 154, the two muscular impressions are seen at 1 and 2; the impression of the margin of the mantle (*pallial impression,* as it is called) at *p p*; and, in Fig. 154, the siphon is indicated by a deep sinus in the pallial impression at *s.* In 155, the shell of an oyster, there is only one muscular impression

2. Ascidians.

Ascidians have a leathery or membranous exterior, bag-like, with two openings, one for the admission of water and food, the other for the exit of excretions. The name is from the Greek ἀσκός, *a leather wine-bottle.* Having no shell, they are not yet known among fossils. Yet it is probable that they were among the earliest kinds of Mollusks.

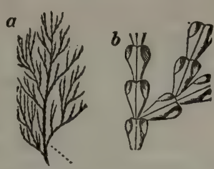
3. Brachiate Mollusks.

1. **Brachiopods.** — Brachiopods (Figs. 150, 151, and 218 to 246, pp. 171–173) have a bivalve shell, and in this respect are like ordinary bivalves. But the shell, instead of covering the right and left sides, covers the dorsal and ventral sides, or its plane is at right angles to that of a clam. Moreover, it *is symmetrical in form, and equal, either side of a vertical line a b,* Fig. 150 (p. 119). The valves, moreover, *are almost always unequal; the larger* is the *ventral,* and the other the *dorsal.* There is often an aperture at the beak (near *b,* Fig. 150), which gives exit to a pedicel by means of which the animal is fixed to some support. In Fig. 151, p. 119, representing a species of the genus *Lingula,* the fleshy support is a long one implanted in the sand by burrowing.

These Brachiopods are also peculiar in other points of structure. They have a *pallium,* but no independent branchial leaflets. They have a pair of coiled fringed arms, which in some Brachiopods may be extruded (Fig. 226), — whence the name Brachiopod, meaning *arm-like foot.* For the support of these arms, there are often bony processes in the interior of the shell, of diverse forms in different genera (Figs. 218, 222, and 225.) These arms serve to keep up a current of water over or through the brachial cavity of the animal.

2. **Bryozoans.** — Bryozoans, or *moss-animals* (so named with reference to the moss-like corals they often form), look like polyps, owing to the series of slender ciliated organs surrounding the mouth, as represented in Figs. 152, 152 *a*, p. 119. 152 is magnified about eight times; and 152 *a* represents the animal, showing its stomach at *s*, and the flexure in the alimentary canal, with its termination along side of the mouth. The corals consist of minute cells either in branched, reticulated, or incrusting forms. They are often calcareous; and such were common in the Silurian, and still occur. *Eschara, Flustra, Retepora* are names of some of the genera.

Fig. 169 A.



BRYOZOAN, Gemellaria loricata

Fig. 169 A represents a membranous species (called *Gemellaria loricata*); *a* is the moss-like coral, natural size; and *b* a portion of a branch, enlarged, showing the cells. Bryozoans are also called *Polyzoans*.

IV. RADIATES.

The sub-kingdom of Radiates contains *three* classes: —

1. ECHINODERMS. — Having the exterior more or less calcareous, and often furnished with spines; and having distinct nervous and respiratory systems and intestine, as the *Echinus* (Fig. 143), *Star-fish* (Fig. 144), *Crinoid* (Fig. 145). The name is from *echinus, a hedgehog,* in allusion to the spines.

2. ACALEPHS. — Having the body usually nearly transparent or translucent, looking jelly-like; and internally a stomach-cavity, with radiating branches. *Ex.*, the Medusa, or jelly-fish (Fig. 140), which generally floats free, when in the adult stage, with the mouth downward; the *Hydra* and allied species are here included.

3. POLYPS. — Fleshy animals, like a flower in form, having above, as seen in Figs. 137, 138, a disk, with a mouth at centre, and a margin of tentacles; internally, a radiated arrangement of fleshy plates; and living for the most part attached by the base to some support. *Ex.*, the *Actinia*, or *Sea-Anemone*, and the animals of ordinary *corals*.

All these classes commence in the Lower Silurian; and some of their sub-divisions are therefore here mentioned.

1. **Echinoderms.** 1. *Holothurioids* or *Sea-slugs.* — Having the exterior soft, and throughout extensile or contractile, and the body elongated; mouth at one end surrounded by a wreath of branched tentacles. It includes the *Biche de mar*, or *Sea-cucumber*.

2. *Echinoids* or *Sea-urchins.* — Having a thin and firm hollow shell, covered externally with spines (Fig. 143); form, spheroidal to disk-shape; the mouth below, at or near the centre, as the *Echinus*, Fig. 143.

Fig. 143 represents an Echinus partly uncovered of its spines, showing the shell beneath, and 147 another, wholly uncovered. The shell consists of polygonal pieces, in twenty vertical series, arranged in ten pairs, except in species of the Paleozoic. *Five* of these ten pairs are perforated with minute holes, and are called the *ambulacral* series (*a* in Fig. 143 represents one pair); and the other five, alternating with these, are called the *inter-ambulacral* (*b*). The inter-ambulacral areas have the surface covered with tubercles, and the tubercles bear the spines, which are all movable by means of muscles. The ambulacral have few smaller tubercles and spines, or none: but over each pore (or rather each pair of pores) the animal extends out a slender fleshy tentacle or feeler, which has usually a sucker-like termination and is used for clinging or for locomotion. In Fig. 147, the inter-ambulacral areas are broad and the plates large, but the ambulacral are narrow and the plates indistinct.

The *mouth*-opening is situated below, at the centre of radiation of the plates.

The *anal* opening in the *Regular* Echinoids (Fig. 143) is in the opposite or dorsal area or centre of radiation. Around the dorsal area there are five minute ovarian openings.

In the *Irregular* Echinoids — constituting a large group — the *anal* opening is to one side of this dorsal centre of radiation, and often on the ventral or under surface of the animal. In Fig. 147, for example, the anal opening is marginal instead of central, while the ovarian pores are around the dorsal centre, as in the *Regular* Echinoids.

To one side of the dorsal centre in the Regular Echinoids, there is a small porous prominence on the shell, often called the *madreporic* body, from a degree of resemblance in structure to coral. In some of the *Irregular* Echinoids, this madreporic body is *in* the centre of dorsal radiation.

The ambulacral areas are sometimes perforated throughout their whole length. But in other cases only a dorsal portion is conspicuously perforated, as in Fig. 147, and, as this portion has in this case some resemblance to the petals of a flower, the ambulacra are then said to be *petaloid*. A large part of Echinoids have a circle of five strong, calcareous jaws in the mouth; in a portion of the *Irregular* Echinoids there are *no* jaws.

3. *Asterioids* or the *Star-fishes.* — Having the exterior stiffened with articulated calcareous granules or pieces, but still flexible; form star-shaped or polygonal; the viscera extending into the arms; mouth below, at centre; arms or rays with a groove on the lower side, along which the locomotive suckers protrude through perforated plates; eyes at the tips of the arms. *Ex.*, the *Star-fish*, Fig. 144.

4. *Ophiuroids* or *Serpent-Stars.* — Having a disk-like body with a star-shaped mouth beneath, and long, jointed, flexible arms, which sometimes subdivide by forking, but never bear pinnæ, and have no grooves along the under side, nor eyes at the slender tips. The viscera do not extend into the arms; the ovarial openings are slit-like, between the bases of the arms; and there is no anal orifice.

5. *Crinoids* (*including Comatulids*). — Like ordinary star-fishes in having flexible arms or rays; but the calcareous secretions of the rays and body constitute a series of closely-fitting solid pieces, and the viscera are confined to the body portion. The rays are often very much subdivided, and bear pinnæ, in which the generative organs are situated.

There are three tribes of Crinoids:—

(1.) The *Crinidea* or *Encrinites.* — Having a regular radiate struc-

ture, and arms proceeding from the margin of the disk; also a stem, consisting of calcareous disks, by which, when alive, they are attached to the sea-bottom or some support, so that they stand in the water and spread their rays, like flowers, the mouth being at the centre of the flower. One of the Crinoids is represented in Fig. 145, and another in Fig. 148, p. 118, the upper part of the figure in each showing the rays closed up, and the lower part the stem. The rays open out, when alive, and then the animal has its flower-like aspect. The little pieces that make up the stem, looking like button-moulds, are either circular, as in Fig. 145 *a*, or five sided, as in Figs. 148 *a*, *b*, *c*, *d*. Under the Crinidea falls the *Comatula family*, the species of which are free when adult, but have slender arms proceeding from the back surface for attachment.

(2.) The *Blastoidea* or *Pentremitids.* — Having a symmetrical ovoidal body, with five petal-like ambulacra meeting at the summit, without proper arms, and attached by a stem like that of the Crinids.

(3.) The *Cystidea* (from the Greek for *a bladder*), Fig. 146. — Arrangement of the plates not regularly radiate. Arms, when present, proceeding from the centre of the summit instead of the margin of a disk; in some, only two arms; in others, replaced by radiating ambulacral channels, which are sometimes fringed with pinnules.

In ancient Crinids, the arms are not generally free down to the base, but there is a union of their lower part, either directly or by means of intermediate plates, into a cup-shaped *body* or *calyx* (as in Fig. 145, and also Figs. 577, 578, under the Carboniferous age, p. 298).

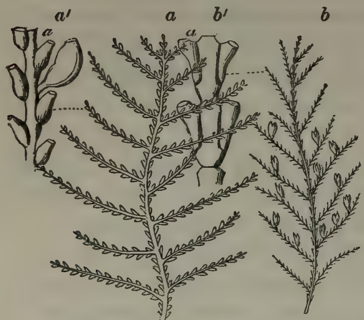
In Fig. 149, the plates of one of these cups, in the species *Batocrinus longirostris* M. are spread out, the bottom plates of the cup being at the centre. The plates, it is seen, are in five radiating series, corresponding to the five rays or arms of the Crinid, and between are intermediate pieces. The three plates numbered 1 are called the *basal*, as the stem is articulated to the piece composed of them; 3, 3, 3 are the *radial*; 4, 4, *supra-radial*; 5, *brachial*, situated at the base of the arms; 7 are intermediate plates, called *inter-radial*; 8, another intermediate, the *inter-supraradial*. Sometimes, in other Crinids, there is another series of plates, at the junction of the plates 1 and 3, called *sub-radial*. Finally, the anal opening of a Crinid is situated toward one side of the disk, it being lateral, as in the Echinoid in Fig. 147; and the intermediate group plates numbered 10 are called the *anal*.

In the Cystids, the aperture is generally lateral and remote from the top, as in Fig. 146, while the arms come out often from the very centre. The Cystids are also peculiar in what are called *pectinated rhombs* (see Fig. 146); that is, rhombic areas crossed by fine bars and openings: the use of them is uncertain, — though they are probably connected with an aquiferous system and respiration. The Cystids are the most anomalous of Radiates.

2. Acalephs. — The free jelly-like Acalephs have very rarely left any traces in the strata. But, besides these, many kinds pass, in their development, through a polyp-like state, and, as the common *Hydra* of fresh waters is included among them, the species are called

Hydroids. Many of them *make corals*, and hence are common as fossils. Fig. 141 represents a Hydra enlarged, with a young one budded out from its side. Some species of the group, — those of the *Sertularia* tribe, — form delicate membranous corals, such as are represented in Fig. 169 B, in which each notch on the little branchlets corresponds to the cup-shaped cell from which an animal protrudes its flower-shaped head. (*a* is the *Sertularia abietina ; b, S. rosacea ;* and *a′*, *b′*, portions of branches enlarged). The interior cavities of each animal communicate freely with the tube in the stem ; and in this they differ from Bryozoans, whose groups have no tubular axis. The ancient *Graptolites* (some of which are represented on page 187) are supposed to have been of this nature. Others secrete calcareous corals of large size, and are called *Millepores* (because the minute cells from which the animals protrude are like pin-punctures in size, and very numerous over the surface of the coral). The Millepores are common in the West Indies and other coral seas. The minute animals of a Millepore have nearly the form represented in Fig. 142, p. 117, which represents a species of another genus, called *Syncoryne.*

Fig. 169 B.



Figs. *a*, *a′*, Sertularia abietina ; *b*, *b′*, S. rosacea.

There are hence stony corals made by Polyps, by Hydroid Acalephs, and by Bryozoan Mollusks.

3. Polyps. — There are two groups of coral-making polyps : —

1. Actinoid Polyps, illustrated in Figs. 137, 138, which make all ordinary corals. The rays or tentacles of the polyps are of variable number, and naked (not fringed).

The coral is secreted within the polyps, as other animals secrete their bones. *It is internal, and not external.* It is usually covered with radiate cells, each of which corresponds to a separate polyp in the group. The rays of a cell correspond to the spaces between fleshy partitions in the interior of the polyp. The material is carbonate of lime (limestone) ; and it is taken by the polyp from the water in which it lives, or from the food it eats.

2. Alcyonoid Polyps, illustrated in Fig. 139, which make the Gorgonia and Alcyonium corals. The rays of the polyps are *eight* in number, and fringed. The figure represents a part of a branch of a Gorgonia (Sea-Fan), with one of the polyps expanded. The branch

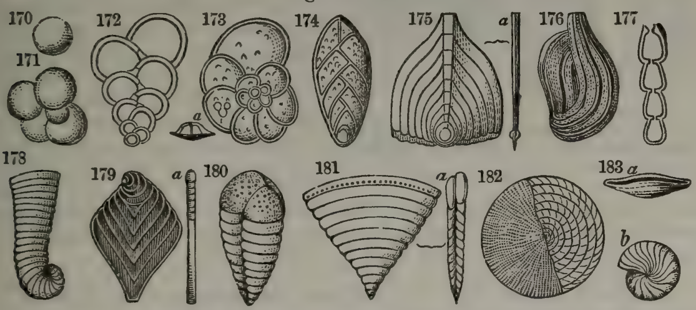
consists of a black horny axis and a fragile crust. The crust is partly calcareous, and consists of the united polyps; the axis of horn is secreted by the inner surface of the crust. The Precious Coral used in jewelry comes from the shores of Sicily and some other parts of the Mediterranean, and belongs to this Alcyonoid division. It is related to the Gorgonias, but the axis is red and stony (calcareous) instead of being horny; and this stony axis is the coral so highly esteemed.

V. Protozoans.

The groups of Protozoans of special interest to the geologist are three: —

1. Rhizopods (Foraminifers). — Species mostly microscopic, often forming shells. The shells, with few exceptions, are very minute, — much smaller than the head of a pin. The most common kinds have calcareous shells called *foraminifers* (from *foramen*), and these have contributed largely to the formation of limestone strata. They consist of one or more cells; and the compound kinds present various shapes, as illustrated in the annexed cut. The arrangement in a group is usually alternate or spiral.

Figs. 170–183.



Figs. 170 to 183. — Rhizopods, much enlarged (excepting 182, 183). Fig. 170, Orbulina universa; 171, Globigerina rubra; 172, Textilaria globulosa *Ehr.*; 173, Rotalia globulosa; 173 *a*, Side-view of Rotalia Boucana; 174, Grammostomum phyllodes *Ehr.*; 175 *a*, Frondicularia annularis; 176, Triloculina Josephina; 177, Nodosaria vulgaris; 178, Lituola nautiloides; 179, *a*, Flabellina rugosa; 180, Chrysalidina gradata; 181 *a*, Cuneolina pavonia; 182, Nummulites nummularia; 183 *a*, *b*, Fusulina cylindrica. All but the last two magnified 10 to 20 times.

Fig. 170 is a one-celled species; the others are compound, and contain a number of exceedingly minute cells. A few are comparatively large species, and have the shape of a disk or coin, as Fig. 182, a *Nummulite*, natural size; the figure shows the interior cells of one-half: these cells form a coil about the centre. *Orbitoides* is the name of another genus of coin-like species. Fig. 183 *a* is a species of *Fusulina*, a kind nearly as large as a grain of wheat, related to the Nummulites; 183 *b* is a transverse view of the same. This is one of the ancient forms of Rhizopods, occurring in the rocks of the Coal formation.

The cells of Rhizopods are each occupied by a separate animal or

zoöid, though each is organically connected with the others of the same group or shell. The animal is of the simplest possible kind, having generally no mouth or stomach, and no members except slender processes of its own substance, which it extrudes through pores in the shell if it have any.

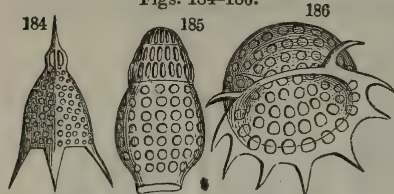
The above are shell-making species of Rhizopods. The name *Rhizopods* comes from the Greek for root-like feet, — in allusion to the root-like processes they throw out. The name *Foraminifer* alludes to the pores. Some of the species not secreting shells (as in the genus *Amœba*) have been seen to extemporize a mouth and stomach. When a particle of food touches the surface, the part begins to be depressed, and finally the sides of the depression close over the particle, and thus mouth and stomach are made when needed; after digestion is complete, the refuse portion is allowed to escape.

The shells of some Rhizopods do not consist of distinct cells: the aggregate living mass secretes carbonate of lime, without retaining the distinction of the zoöids. This is the case, as Carpenter has observed, in the Nummulite-like genus *Orbitolites*. Some species make large coral-like masses instead of small shells.

Other Rhizopods make shell-shaped coverings out of the grains of sand or other material at hand, agglutinating them.

Other forms, called *Polycystines*, secrete siliceous shells; and these shells are symmetrically radiate or circular. They are common in many seas. Three species, from the Barbadoes, are represented in Figs. 184 to 186. Fig. 184, *Lychnocanium Lucerna* Ehr.; Fig. 185, *Eucyrtidium Mongolfieri* Ehr.; Fig. 186, *Halicalyptra fimbriata* Ehr., the first two magnified 100 diameters, the last about 75. From these deeply concave forms, there are gradations in one direction to disks with concave centres, and to flat disks, both with plain and pointed borders, and in the other direction to elongate, conical and spindle-shaped forms. Others have the shape of a flattened cross; another is an open diamond, with narrow diagonals and periphery. The disks have a *concentric*, and not a spiral, structure, and thus are unlike those of Nummulites. For figures, see Ehrenberg's "Mikrogeologie," and Bailey in "Amer. Jour. Sci.," II. xxii. pl. 1.

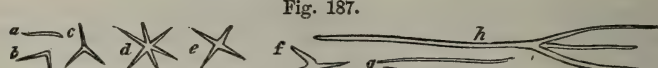
Figs. 184–186.



184, Lychnocanium Lucerna (× 100); 185, Eucyrtidium Mongolfieri (× 100); 186, Halicalyptra fimbriata (× 75).

2. Sponges. — Sponges are regarded as compound animals. The animals, according to H. J. Clark, belong to the division of *flagellate* Protozoans, a kind (including the genus *Monas*, etc.) in which there is a short filament (or *flagellum*) adjoining the mouth. The interior surface of the tubes of a sponge is made up of a closely-packed layer of

Fig. 187.

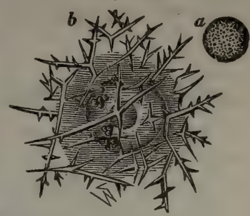


Siliceous spicula of Sponges.

the zoöids, their anterior or mouth extremities projecting freely into the general cavity. The material of the common sponges is ordinarily like horn in its nature; but in most kinds there are minute siliceous

spicula sticking out from the sides of the fibres. Some of the siliceous spicula are shown enlarged in Figs. 187 *a–h*. Many deep-sea species consist mainly of siliceous fibres. They look as if made of spun glass worked together into forms of great delicacy and beauty. The annexed figure represents, much enlarged, a species of sponge — a jelly-like globule of minute size — which sometimes beclouds the sea in the Pacific. (It is from the East Indian seas, and is named *Sphærozoum orientale* D.) It is bristled with spicula. The death and decay of such sponges would add largely to the silica of the sea bottom.

Fig. 188.



Some sponges secrete *calcareous* spicula instead of siliceous; and there are others that are chiefly calcareous in their constitution, and consequently look like masses of a compact coral. The large corals referred to the genus *Stromatopora*, and others allied, are regarded by some zoölogists as either calcareous sponges or foraminifers.

3. VEGETABLE KINGDOM.

The vegetable kingdom is not divisible into sub-kingdoms like the animal; for the species all belong to one grand type, the Radiate, the one which is the lowest of those in the animal kingdom. The following are the higher subdivisions.

I. Cryptogams. — Having no distinct flowers or proper fruit, the so-called seed being only a *spore*, that is, a simple cellule without the store of nutriment (albumen and starch) around it which makes up a true seed; as the Ferns, Sea-weed. They include —

1. *Thallogens.* — Consisting wholly of cellular tissue; growing mostly in fronds without stems, and in other spreading forms; as (1) Algæ, or Sea-weeds; (2) Lichens; (3) Fungi, or Mushrooms.

2. *Anogens.* — Consisting wholly of cellular tissue; growing up in short, leafy stems; as (1) Musci, or Mosses; (2) Liverworts.

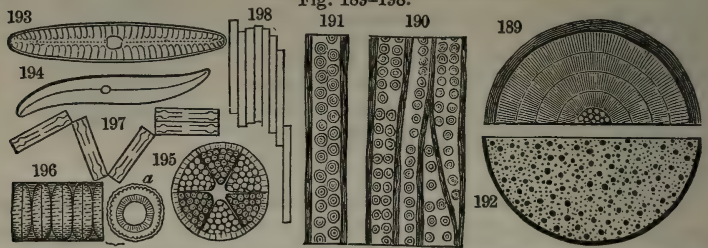
3. *Acrogens.* — Consisting of vascular tissue in part, and growing upward; as (1) Ferns; (2) Lycopods (Ground-Pine); (3) Equiseta; and including many genera of trees of the Coal period.

II. Phenogams. — Having (as the name implies) distinct flowers and seed; as the Pine, Maple, and all our shade and fruit trees, and the plants of our gardens. They are divided into —

1. *Gymnosperms.* — *Exogens*, or *Exogenous* in growth: that is, the plant has a bark, and grows by an addition annually to the exterior of the wood, between the wood and the bark, and hence the wood shows in a transverse section *rings of growth*, each the formation of a single year

(Fig. 189). (This mode of growth is in contrast to that which characterizes the Endogens.) The flowers exceedingly simple, and the *seed naked*, — the seed being ordinarily on the inner surface of the scales of cones. Examples are the Pine, Spruce, Hemlock, etc. The name Gymnosperm is from the Greek for *naked seed*. Gymnosperms include (1) *Conifers;* (2) *Cycads* (p. 408).

Fig. 189–198.



PLANTS. — Fig. 189, section of exogenous wood; 190, fibres of ordinary coniferous wood (Pinus Strobus), longitudinal section, showing dots, magnified 300 times; 191, same of the Australian Conifer, Araucaria Cunninghami; 192, section of endogenous stem.

Figs. 193 to 198, DIATOMS highly magnified; 193, Pinnularia peregrina, Richmond, Va.; 194 Pleurosigma angulatum, id; 195, Actinoptychus senarius, id; 196, Melosira sulcata, id; *a*, transverse section of the same; 197, Grammatophora marina, from the salt water at Stonington, Conn.; 198, Bacillaria paradoxa, West Point.

The wood of the Conifers is simply woody fibre without ducts, and, in this respect, as well as in the flowers and seed, this tribe shows its inferiority to the following subdivision. The fibre, moreover, may be distinguished, even in petrified specimens, by the dots along the surface as seen under a high magnifier. The dots look like holes, though really only thinner spaces. Fig. 190 shows these dots in the *Pinus Strobus.* In other species, they are less crowded. In one division of the Conifers, called the *Araucariæ*, of much geological interest, these dots on a fibre are alternated (Fig. 191); and the Araucarian Conifers may thus be distinguished.

2. *Angiosperms.* — Exogens, like the Gymnosperms. Having regular flowers and also *covered seed;* as the Maple, Elm, Apple, Rose, and most of the ordinary shrubs and trees. Called *Angiosperms*, because the seeds are in seed-vessels; and also *Dicotyledons*, because the seed has two cotyledons or lobes.

3. *Endogens.* — Regular flowers and seed; but growth endogenous, the plants having no bark, and showing, in a transverse section of a trunk, the ends of fibres, and no rings of growth (Fig. 192): as the Palms, Rattan, Reed, Grasses, Indian Corn, Lily. The Endogens are *Monocotyledons;* that is, the seed is undivided, or consists of but one cotyledon.

Among Algæ, three kinds are of prominent interest to the geologist: —

1. *Fucoids*, or those related to the tough leathery sea-weeds along coasts, which are called *Fuci*, some of which, among modern species, grow to a great size, attaining a length even of hundreds of feet.

2. *Plants having calcareous secretions.* Among these there are (1) the delicate *Corallines*, which have generally a jointed stem, and are only imperfectly calcareous; (2) the *Nullipores*, which are often like stony corals in form and hardness, making incrustations, and also branching more or less perfectly: they differ from corals in having no pores or cells, not even the pin-punctures of the Millepores; (3) *Coccoliths*, lenticular calcareous disks, usually convexo-concave, less than a thousandth of an inch in diameter, occurring in many places over the ocean's bottom, and also in shallow waters. Named from κόκκος, *seed*, and λίθος, *stone*.

3. *Plants having siliceous secretions.* Microscopic, and mostly unicellular plants. The *Diatoms* secrete a siliceous shell; and they grow so abundantly in some waters, fresh or salt, as to produce large siliceous accumulations. A few of these siliceous species are figured above, in Figs. 193 to 198.

There are also microscopic species called Desmids, that consist of one or a few greenish cells, and secrete little or no silica. They do not contribute largely to rock-making, like the *Diatoms*, but are common as fossils in flint and other siliceous concretions. Some are figured on page 257, Fig. 484 A.

The minute plants of the waters are sometimes called *Protophytes*.

The *Charæ* are other Cryptogamous plants, having large *calcareous* secretions. They are delicate aquatic species, in some respects related to the Mosses. The dried plant affords 30 per cent. of ash, 95 per cent. of which is carbonate of lime. Consequently, when abundant, they contribute calcareous material to the bottoms of ponds.

PART III.

HISTORICAL GEOLOGY.

GENERAL DIVISIONS IN THE HISTORY.

1. Nature of subdivisions in history. — The methods of ascertaining the true succession or chronological order of the rocks have been explained on pages 101 to 107. Some further explanations are necessary, by way of introduction to the survey of geological history.

What are subdivisions in history? — Many persons, in their study of geology, expect to find strongly-drawn lines between the ages, or the corresponding subdivisions of the rocks. But geological history is like human history in this respect. Time is one in its course, and all progress one in plan.

Some grand strokes there may be, — as in human history there is a beginning in man's creation, and a new starting-point in the advent of Christ. But all attempts to divide the course of progress in man's historical development into ages with bold confines are fruitless. We may trace out the culminant phases of different periods in that progress, and call each culmination the centre of a separate period. But the germ of the period was long working onward in preceding time, before it finally came to its full development and stood forth as the characteristic of a new era of progress. It is all one progress, while successive phases stand forth in that progress.

In geological history, the earliest events were simply physical. While the inorganic history was still going on (although finished in its more fundamental ideas), there was, finally, the introduction of *life*, — a new and great step of progress. That life, beginning with the lower grades of species, was expanded and elevated, through the appearance of new types, until the introduction of Man. In this organic history, there are successive steps of progress, or a series of culminations. As the tribes, in geological order, pass before the mind, the reality of one age after another becomes strongly apparent. The age of Mammals, the age of Reptiles, and the age of Coal-plants come out to view, like mountains in the prospect, — although, if the

mind should attempt to define precisely where the slopes of the mountain end, as they pass into the plain around, it might be greatly embarrassed. It is not in the nature of history to be divided off by visible embankments; and it is a test of the true philosopher to see and appreciate the commencements and culminations of phases, or of the successive ideas, in the system of progress, amid the multitude of events and indefinite blendings that bewilder other minds.

We note here the following important principles: —

First. The reality of an age in history is marked by the development of some new idea in the system of progress.

Secondly. The beginning of the characteristics of an age is to be looked for in the midst of a preceding age; and the marks of the future coming out to view are prophetic of that future.

Thirdly. The end of an era may come, either after the full culmination of the idea or phase, or, earlier, at the commencing prominence of a new and grander phase in the history. It may be as ill-defined as the beginning, although its prominent idea may stand out boldly to view. Thus the age of Coal-plants was preceded by the occurrence of related plants far back in the Devonian. The age of Mammals was foreshadowed by the appearance of mammals long before, in the course of the Reptilian age. And the age of Reptiles was prophesied in types that lived in the earlier Carboniferous age. Such is the system in all history. Nature has no sympathy with the art which runs up walls to divide off her open fields.

But the question may arise, whether a geological age is not, after all, strongly marked off in the rocks. Rocks are but the moving sands or the accumulations of dead relics of the age they represent, and are local phenomena, as already explained. Each continent has its special history as regards rock-making; and it is only through the fossils in the rocks that the special histories can be combined into a general system. The movements which have disturbed one continent have not affected in precisely the same manner the rest, although there has sometimes been a general parallelism in the changes of level; and hence there are breaks in the succession of rocks on one continent, or part of a continent, that have no representatives on another.

When an age can be proved, through careful study, to have been closed by a catastrophe or a transition which was universal in its effects, the event is accepted as a grand and striking one in geological history. But the proof should be obtained, before the universality is assumed. Hence the conclusion, —

Fourthly. The grander subdivisions or ages in geological history, based on organic progress, should be laid down independently of the

rocks. They are universal ideas for the globe. The rocks are to be divided off as nearly as practicable in accordance with them.

Each continent, under these ages, then becomes a special study; and its history has its periods and epochs which may or may not correspond in their limits with those of the other continents. Every transition in the strata, as from limestone to sandstone, clay-beds or conglomerate, or from either one to another, and especially where there is also a striking change in the organic remains, indicates a transition in the era from one set of circumstances to another, — it may be a change from one level to another in the continents, a submergence or emergence, or some other kind of catastrophe. All such transitions mark great events in the history of the continent, and thus divide the era into periods, and may further subdivide the periods into epochs. Hence, —

Fifthly. Through the ages, the different continents, and often also the distant regions of the same continent, had their special histories; and the periods and epochs are indicated by changes or transitions in the rock-formations of the region and in their fossils.

The periods and epochs of America and Europe are not in general the same in their limits, and much less in their rocks. The Devonian age, for example, has a very different series of periods and epochs in North America from what it has in Europe, and there is even considerable diversity between the subdivisions in New York and the Atlantic slope, and those of the Mississippi valley. It is far from certain that the commencement assigned to the Devonian in North America is synchronous with that for Europe. The Carboniferous, Reptilian and Mammalian ages also have their American epochs and their European differing from one another; and the differences between the continents increase as we come down to more modern times. We add, therefore, —

Sixthly. It is an important object in geology to ascertain as nearly as possible the parallelism between the periods and epochs marked off on each continent, and to study out the *equivalents* of the rocks, each for each, that all the special histories may read as parts of one general history, and thus contribute to the perfection of one geological system.

Subdivisions based on the progress of life. — In accordance with the principles explained, the following subdivisions of geological time are here adopted.[1]

[1] The system of ages is essentially the same with that proposed by Professor Agassiz, — the only difference consisting in calling the Silurian the age of Invertebrates, as suggested by Murchison, instead of considering both the Silurian and Devonian the age of Fishes.

I. Archæan Time. — The beginning, including a very long era without life, and, finally, that in which appeared the earliest and simplest forms of plants and animals.

II. Silurian Age, or Age of Invertebrates. — The animal life consisting distinctively of Invertebrates.

III. Devonian Age, or Age of Fishes. — Fishes, a division of Vertebrates (the earliest of which had appeared before the close of the Silurian), the dominant race.

IV. Carboniferous Age, or Age of Acrogens, and eminently also the Age of Amphibians. — Characterized by Coal-plants, which were chiefly of the tribe of Acrogens, — a tribe that then had its grandest exhibition; and in animal life, by the earlier Reptiles, belonging mostly to the lower division, Amphibians.

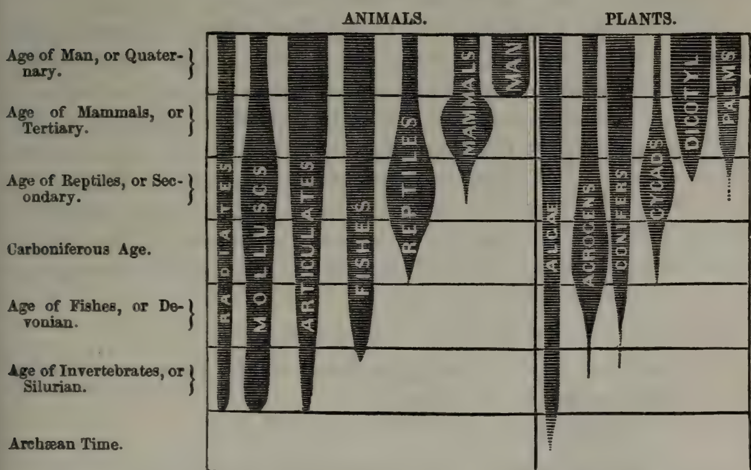
V. Age of Reptiles. — Reptiles the dominant race.

VI. Tertiary Age, or Age of Mammals. — Mammals the dominant race.

VII. Quaternary, or Age of Man.

The general facts in the progress of life on the globe are illustrated in the annexed diagram, —

Fig. 200.



The horizontal bands represent the ages, in succession; the vertical correspond to different groups of animals and plants. The lower end of each vertical band marks the point in geological time when, *according to present knowledge from fossils*, the type it represents began; and the varying width in the same bands indicates the greater or less expansion of the type. The following are accordingly the points the diagram illustrates: —

Radiates began with the commencement of the Silurian, and have continued till now, rather increasing throughout the ages.

Mollusks had their beginning at the same time, and continued increasing to the age of Reptiles: they then passed their maximum (as indicated in the figure).

Articulates commenced in the Silurian (as Crustaceans and Worms), and continued expanding in numbers and grade to the present time.

Fishes began near the close of the Silurian, were very abundant in the Devonian, and continued on, becoming increasingly diversified to the last, with some rise in grade.

Reptiles began in the Carboniferous, and reached their maximum in the Reptilian age.

Mammals began in the Reptilian age, and were the highest race of the Mammalian age.

Sea-weeds (or Algæ) were the earliest plants of the globe, probably preceding animal life. Acrogens and Conifers began in the Upper Silurian. The Acrogens had their greatest expansion in the age of Coal-plants, in which they occurred with Conifers. Cycads began in the Carboniferous, and had their greatest expansion in the Reptilian age. Dicotyledons began in the closing period of the Reptilian age, and expanded, along with Palms, through the age of Mammals.

The Silurian, Devonian, and Carboniferous ages naturally stand somewhat apart from the following ones, in the peculiar ancient forms of the great portion of their living tribes; and to the whole collectively the term PALEOZOIC era is appropriately applied, — the word "paleozoic" being from the Greek παλαιός, *ancient*, and ζωή. The following age, or age of Reptiles, is correspondingly termed the MESOZOIC, from μέσος, *middle*, and ζωή, it being the *mediæval* era in geological history. The Mammalian age is termed the CENOZOIC, from καινός, *recent*, and ζωή. (The words *Eocene*, *Miocene*, etc., subdivisions of the age, are in part from the same root.)

The subdivisions of geological time are, then, —

I. ARCHÆAN TIME, including an Azoic and an Eozoic era though not yet distinguished in the rocks.

1. Azoic Age.
2. Eozoic Age.

II. PALEOZOIC TIME.

1. The Age of Invertebrates, or Silurian.
2. The Age of Fishes, or Devonian.
3. The Age of Coal-plants, or Carboniferous.

III. MESOZOIC TIME.

The Age of Reptiles.

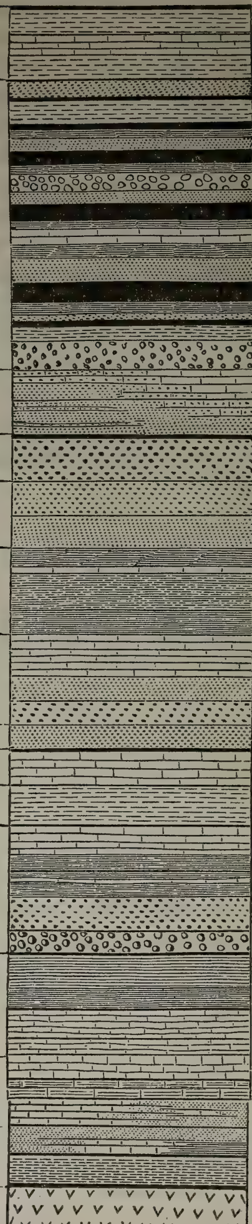
IV. CENOZOIC TIME.

1. The Tertiary, or Age of Mammals.
2. The Quaternary, or Age of Man.

Subdivisions into Periods and Epochs.—The subdivisions under the ages, the periods and epochs, vary, as has been said, in different countries. The following table (Fig. 201) presents a general view of those of eastern North America, so far as the Paleozoic is concerned,—the Silurian, Devonian, and Carboniferous being well represented on the North American continent. The rest of the series is from European geology, in which the later ages are far better represented than in America. In this Manual, American geology is in general first considered; and afterward such further illustrations are drawn from other continents as are necessary for comprehensive views and generalizations. Where America is deficient in its records, the European are taken as the standard.

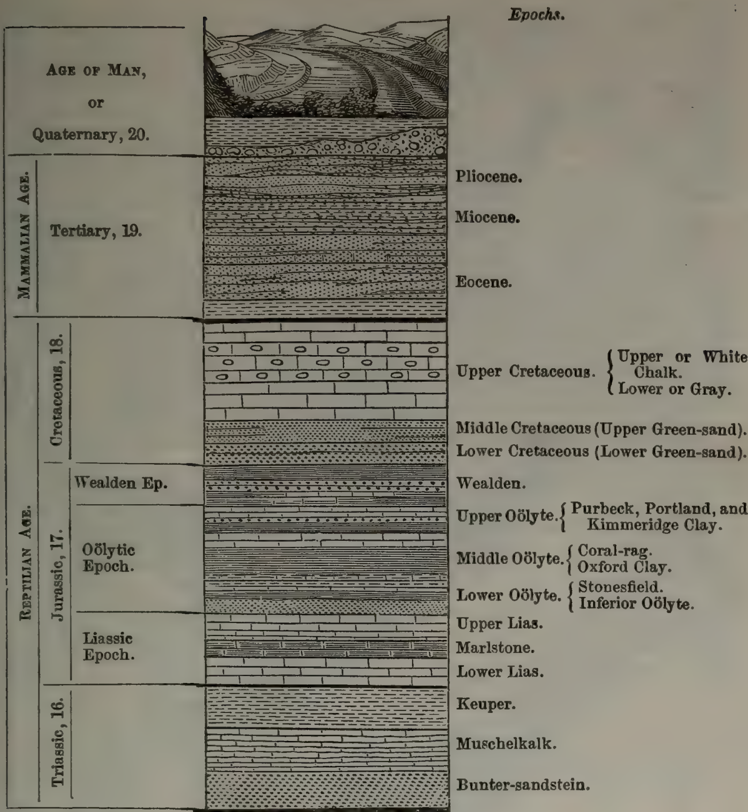
The names of the periods and epochs for the Paleozoic of America are, in the main, the same that have been applied to the rocks by the New York geologists.

Fig. 201.



Age		*Periods.*		*Epochs.*
Carboniferous Age.		Permian.	15	Permian.
		Carboniferous.	14c	Upper Coal Measures.
			14b	Lower Coal Measures.
			14a	Millstone Grit.
		Subcarboniferous.	13b	Upper.
			13a	Lower.
Devonian Age, or Age of Fishes.		Catskill.	12	Catskill.
		Chemung.	11b	Chemung.
			11a	Portage.
		Hamilton.	10c	Genesee.
			10b	Hamilton.
			10a	Marcellus.
		Corniferous.	9c	Corniferous.
			9b	Schoharie.
			9a	Cauda-Galli.
Silurian Age, or Age of Invertebrates.	Upper Silurian.	Oriskany.	8	Oriskany.
		Lower Helderberg.	7	Lower Helderberg.
		Salina.	6	Salina.
		Niagara.	5c	Niagara.
			5b	Clinton.
			5a	Medina.
	Lower Silurian.	Trenton.	4c	Cincinnati.
			4b	Utica.
			4a	Trenton.
		Canadian.	3c	Chazy.
			3b	Quebec.
			3a	Calciferous.
		Primordial or Cambrian.	2b	Potsdam.
			2a	Acadian.
		Archæan.	1	Archæan.

Fig. 201 (*continued*).



In the figures and maps introduced beyond, the numbers are used as in the above tables: 1 standing for the Archæan; 2 for the rocks of the Primordial, 3 for the rocks of the Canadian period; 3 *a*, 3 *b*, 3 *c*, for its subdivisions; 4 for rocks of the Trenton period, 4 *a*, 4 *b*, 4 *c*, for the epochs of this period; and so on.

The following map of the United States east of the Rocky Mountains exhibits the geographical distribution of the rocks of the several ages, — that is, the regions over which they are severally the *surface-rocks.*

The *Silurian* is distinguished by heavy horizontal lining.

The *Devonian*, by heavy vertical lines.

The *Carboniferous*, by light cross-lines on a black ground, or by a black surface, or by dots on a black ground (the *first* the Subcarboniferous, the *second* the Coal-formation, the *third* the Permian). The black areas are the Coal-areas of the country.

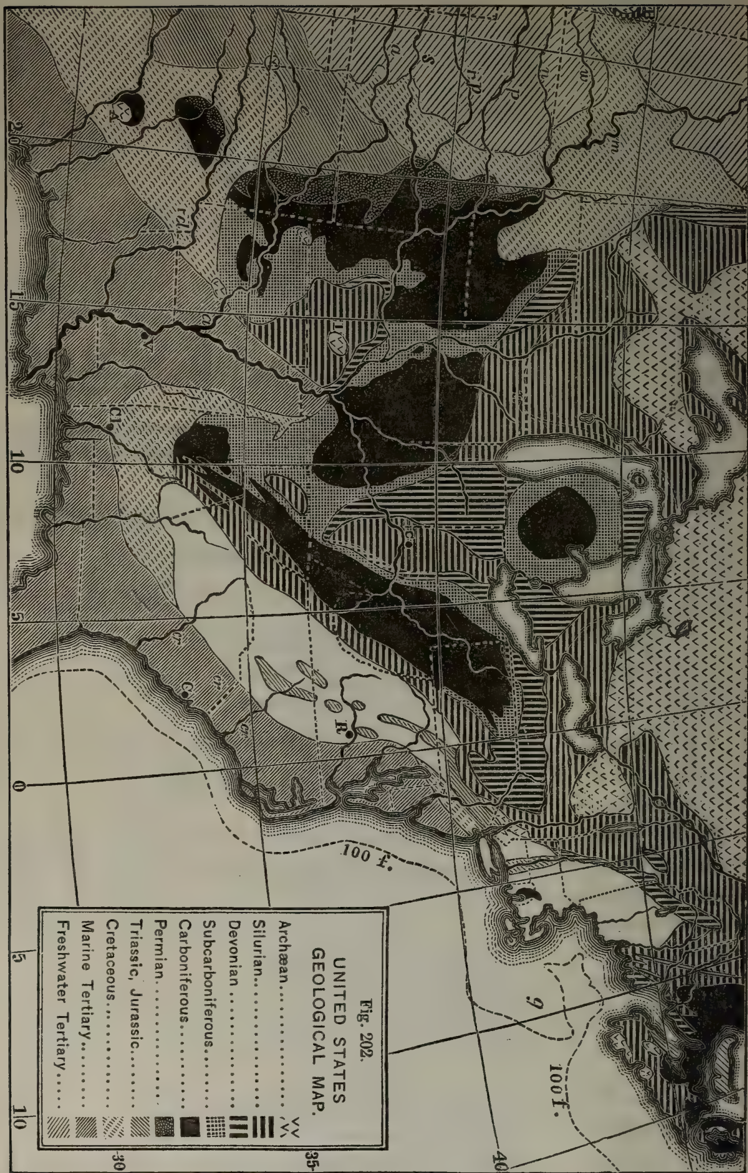


Fig. 202.
UNITED STATES
GEOLOGICAL MAP.

The *Reptilian*, including the Triassic, Jurassic, and Cretaceous, by lines sloping from the right to the left (⁄), the Cretaceous being distinguished by having the lines broken.

The *Tertiary*, by lines sloping from the left to the right (\ ).

The surface without markings is occupied by rocks of undetermined age; that on the east is mostly crystalline.

In Nova Scotia and New Brunswick, the Subcarboniferous is not distinguished from the Carboniferous; and, west of the Mississippi, the limit between the Carboniferous and Permian areas is partly conjectural; and also that in Arkansas between the Carboniferous and Subcarboniferous. In the lettering, Cr. stands for Cretaceous; C., Charleston, S. C.; Ci., for Cincinnati; V., Vicksburg, Miss.; B., Black Hills; O., Ozark Mountains; W., Witchita Mountains. On rivers, to the west: *w.*, White; *n.*, Niobrara; *p.*, Platte; *rp.*, Republican; *s.*, Smoky Hill; *a.*, Arkansas; *c.*, Canadian; *r.*, Red.

Thickness of the stratified rocks. — The whole thickness of the rocks in the series has been stated at twenty miles or more. But this includes the sum of the whole, grouped in one pile. As the series is nowhere complete, this cannot be said to be the thickness observed in any one region. The rocks of New York, down to the Archæan, counting all as one series, are about 13,000 feet in thickness. They include only the Silurian and Devonian (excepting the Triassic in the southeast). They thin out to a few feet in the northern part of the State, and have their greatest thickness toward Pennsylvania. In Pennsylvania, the rocks include the Carboniferous; and the whole thickness is at least 40,000 feet. This is exclusive of the Triassic, which may add a few thousands to the amount. In Virginia, the thickness is still greater; but no exact estimate has been made. In Indiana and the other States west, it is only 4,000 feet, although extending, as in Pennsylvania, to the top of the Carboniferous. The greater part of the continent of North America east of the Mississippi is destitute of rocks above the Carboniferous.

In Great Britain and Europe, the series of rocks is more complete than in eastern North America. In Great Britain, the thickness to the top of the Silurian is over 60,000 feet; to the top of the Carboniferous, or the Paleozoic, 85,000 feet; then to the close of the series, 100,000. This amount is the sum of the thickest deposits of the several formations, and not the thickness observed in any particular place. On the Continent, there are at least 25,000 feet of strata above the Paleozoic.

Subdivision of the North American continent into regions of partially independent progress. — It is a remarkable fact, illustrated through all American geological history, that the grand features of the continent were early defined; and that, through all time, from the close of the Archæan, if not also before, the ranges of land which are now the courses of the mountain chains, were the boundaries be-

tween great continental basins that were, in a marked degree, independent in the progress of rock-making and of life. The positions of the mountain chains, and of other prominent features of the land, were thus indicated long before they had existence. It will be convenient, therefore, to describe the rocks, and sometimes the life, of each such region separately; and these regions are therefore here enumerated.

1. The *Eastern Border basin or region*, east and northeast of the Green Mountain range, and including New England, Eastern Canada, New Brunswick, western Nova Scotia, the Gulf of St. Lawrence and Newfoundland.

2. The *Appalachian* region, along the course of the Appalachians, through the Green Mountains, to the vicinity of Quebec.

3. The *Interior Continental basin*, between the Appalachians (with the Green Mountains, properly the northern part of them) and the Rocky Mountain chain.

4. The *Western Border basin*, west of the Rocky Mountain summit.

A great Arctic Border region and a Rocky Mountain region may hereafter be recognized; but the facts thus far collected do not at present make it necessary to refer separately to them.

I. ARCHÆAN TIME.

Archæan time includes strictly, as its commencement, an *Azoic* age, or the era in which the physical conditions were incompatible with the existence of life. But this era, so far as now known, is without recognizable records; for no rocks have yet been shown to be earlier in date than those which are now supposed to have been formed since the first life began to exist. About this early era there is, therefore, little known. By following the lead of ascertained law in physics and chemistry, and the suggestions of astronomy, and also analogies from later geological history, some probable conclusions may be reached. But this is not the place for their discussion, except so far as to state the principal steps of progress. There must have been, —

I. A *first* era, after that of the original nebula, if such there was, — in which the earth was a globe of molten rock, like the sun in brightness and nature, enveloped in an atmosphere containing the dissociated elements of the future waters and whatever else the heat at the surface could throw into a state of vapor.

II. A *second* era, in which cooling went forward until the exterior became solid from cooling, and probably as a crust over a liquid inte-

rior; and until, in the second place, the vapors of the atmosphere were mostly condensed, and an envelope of waters, nearly or quite universal, was thus made. Depressions for special oceanic basins would have been early begun, over the cooling and contracting sphere; and it is probable, as elsewhere shown (pp. 160, 816), that the existing continental areas were defined in general contour in this first-formed crust, and that within their confines appeared the first dry land. This crust has since continued cooling and thickening. The hot and acid waters of the condensing vapors and the first oceans began the work of surface erosion and alteration, and of transportation and deposition.

III. A *third* era, or a continuation of the preceding, carrying forward the cooling to 80° or 100° C. (175° to 212° F.), or *to a temperature admitting of the existence of the simplest forms of vegetable life.* Through this era, the crust, by its contraction from cooling, which was in unceasing progress, must have been slowly varying and augmenting its surface reliefs.

At the same time, the wear of the rocks of the *crust*, wherever they were exposed to the ocean's waves or currents, aided by their disintegration where above the waters, would have continued the formation of stratified deposits out of the detritus; and so have added to the series of rocks over the surface that makes up the earth's *supercrust* — the only part of the earth's structure which is within the reach of direct investigation.

At first, the beds of detritus formed in the hot waters (a powerful chemical agent through their heat, and the silica and other materials in solution) would have been consolidating and crystallizing beneath, while accumulation was going on above; and this may have continued to be true throughout the age, and in fact long after the waters had passed the temperature-limit of 100° C. The rocks of this era should therefore be much like those that resulted from the original cooling, because made chiefly out of the latter by reconsolidation and recrystallization, except that schistose and quartzose rocks would have been more common in the new formations.

These Archæan rocks are the only universal formation. They extend over the whole globe, and were the floor of the ocean and the material of all emerged land, when life first began to exist. The thickness which they acquired during the long era from the time of the first-formed crust can never be known.

Professor Helmholtz has calculated, from the rate of cooling of lavas, that the earth, in passing from 2,000° to 200° C., must have taken *three hundred and fifty millions* of years. But the temperature when the Archæan ended was probably not over 38° C. (100° F.), to reach which many more scores of millions of years must have been passed. The era was long.

IV. A fourth era, commencing with the beginning of life on the globe, — which beginning was possible, judging from known facts, when the temperature of the waters had cooled down at least to 200° F. It has been supposed that all the Archæan rocks open to view over the earth's surface are those of this last era. But more investigation is required, before it can be regarded as an established fact that none of earlier time are open to investigation. From these rocks in America, two principal periods have been indicated, with other subdivisions.

I. Distribution of Archæan Regions.

The Archæan rocks of North America are mostly crystalline or metamorphic rocks, and their beds stand at all angles, owing to the uplifting and flexing which they have undergone. Where the Silurian strata overlie them, the two are *unconformable*, the latter being often spread out in horizontal beds over the upturned edges of the Archæan rocks. This position of these rocks is illustrated in the following cuts. In each, the Archæan, numbered 1, in its usual disturbed condition, is overlaid nearly horizontally by the Silurian beds of the Potsdam and other periods, numbered 2 to 4; 2 being the Potsdam sandstone, 3 the Calciferous sandrock, 4 *a* the Trenton limestone, 4 *b* the Utica shale.

Fig. 203.

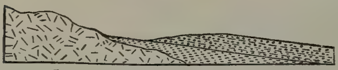


Fig. 204.

Fig. 205.

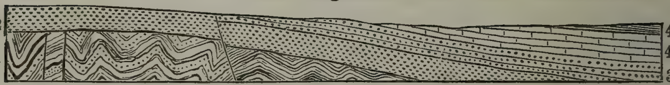


Fig. 203, by Emmons, from Essex County, N. Y.; 1 is hypersthene rock, or hypersthenyte. — Fig. 204, by Owen, from Black River, south of Lake Superior; 1 is a granytic rock, 1 *a*, chloritic and ferruginous slates. — Fig. 205, by Logan, from the south side of the St. Lawrence in Canada, between Cascade Point and St. Louis Rapids; 1, gneiss.

This formation in North America was first distinctly recognized in its true importance in the Report of Foster and Whitney on the Lake Superior region, in which it was named the *Azoic system*. Dawson, after his announcement of the animal nature of the Eozoon, suggested the name *Eozoic* (from ἠώς, *dawn*, and ζωή, *life*). As the supposed Eozoon may be of mineral nature, its use here is objectionable.

The areas of the earth's crust over which the Archæan rocks are now exposed are, —

1. Those which have always remained uncovered.

2. Those which have been covered by later strata, but from which these superimposed beds have been simply washed away, without much disturbance.

3. Those once covered, like the last, but which, in the course of the upturnings of mountain-making, have been pushed upward among the displaced strata, and in this way have been brought out to the light.

In cases like those of figures 203, 204, in which the Silurian rocks are spread in nearly horizontal layers over the borders of an area made up of tilted Archæan rocks, the Archæan area either has been always uncovered, or has become so from denudation; but, in mountain-regions, where the Silurian rocks have been folded up in the mountain-making, the Archæan below may have been brought to view in the upturnings. Moreover, the Archæan, if it had not undergone flexures before the Silurian beds were laid down, would partake of the Silurian flexures, or, in other words, be conformable to the Silurian strata. But, if it had been flexed or tilted in some previous period of disturbance, then the Archæan would be uncomformable to the Silurian, although both were finally upthrown together, in the making of the mountains.

In the study of Archæan regions, these points require special investigation.

Fig. 206.

Archæan Map of North America.

In the map, Fig. 206, the chief Archæan regions are the white areas, while the dark-lined portion represents the rest of the continent submerged beneath the continental sea.

The principal of the areas is *The great northern*, nucleal to the continent, B B C C on the map, lying mostly in British America, and having the shape of the letter V, one arm reaching northeastward to Labrador, and the other northwestward from Lake Superior to the Arctic. The region appears to have been, for the most part, out of water, ever since the Archæan era. To this area properly belong the Adirondack area, covering the larger part of northern New York, and a Michigan area south of Lake Superior, each of which was probably an island in the continental sea before the Silurian age began.

Besides this nucleal area, there are border-mountain lines of Archæan rocks: a long *Appalachian line*, including the Highland Ridge of Dutchess County, N. Y., and New Jersey, and the Blue Ridge of Pennsylvania and Virginia; a long *Rocky Mountain series*, embracing the Wind River mountains, the Laramie range, and other summit ridges of the Rocky Mountains. In addition, in the Eastern Border region, there is an *Atlantic Coast range*, consisting of areas in Newfoundland, Nova Scotia, and eastern New England; in the Western Border region, a *Pacific Coast range* in Mexico; and several more or less isolated areas in the *Mississippi basin*, west of the Mississippi, as in Missouri, Arkansas, Texas, and the Black Hills of Dakota.

The Adirondack area in Northern New York covers for the most part Essex, Clinton, Franklin, St. Lawrence, Hamilton, and Warren counties, and parts of Saratoga, Fulton, Herkimer, Lewis, and Jefferson counties.

In *the Eastern Border* region, Archæan rocks occur in Nova Scotia (near Arisaig); in New Brunswick (near Portland); probably in part of Maine, on the Island of Mount Desert (according to Verrill); and along a range of country running northeastward to New Brunswick; in northeastern Massachusetts, about Newburyport, Chelmsford, and Bolton; and in northeastern Rhode Island.

In central and western New England, there are areas in the White Mountain region, New Hampshire (first announced by C. H. Hitchcock) as at Waterville; and west of the Connecticut, about Winchester, Connecticut (Hall), and the emery region of Chester, Massachusetts, — the titanic iron vein of Winchester and the emery and iron vein of Chester lying nearly in the same line.

The Appalachian areas commence in Dutchess County, New York, west of Connecticut, and extend southwestward to West Point, and thence along the Highlands of New Jersey, the Durham Hills of eastern Pennsylvania and their continuation in South Mountain, and beyond in the Blue Ridge, through western Virginia and North Carolina, into South Carolina, Tennessee, and Georgia.

The map of New York and Canada, in the chapter on the Silurian, shows more precisely the form of the New York Archæan and that north of the St. Lawrence. It represents also the Silurian and Devonian strata of the State, as they become successively the surface-rocks, on going from the Archæan southward. Adjoining the Archæan (numbered 1), is the earliest Silurian, No. 2, which outcrops where it is represented, but is supposed to underlie the strata numbered 3, 4, 5, etc. So No. 3 is the next formation which outcrops, while it probably underlies all the beds 4, 5, etc. The Archæan is thus the lowest; and each successive stratum was a new deposit over it, in the seas that bordered at the time the Archæan dry land.

In the *Rocky Mountain region*, there are long narrow ranges whose limits are not well determined. On the Mexican area, see Am. Jour. Sci., II. xxxix. 309, 1865.

In Europe, the Archæan system has been distinctly recognized in northwestern Scotland; in Finland, Norway, and Sweden; Bohemia (formations A and B of Barrande); Bavaria (Hercynian and Bojic Gneiss). The great iron-regions of Sweden are of this age.

II. Periods of the Archæan Era.

In Canada, where these rocks in North America are most fully represented, two periods have been recognized: 1, The LAURENTIAN, the older, so named from the river St. Lawrence; and 2, the HURONIAN. The estimated thickness of the rocks of the Laurentian period is 30,000 feet; of the Huronian, from 10,000 to 20,000 feet.

1. LAURENTIAN PERIOD.

I. Rocks: Kinds and Distribution.

Geographical Distribution. — The regions of Laurentian rocks comprise all the Archæan above mentioned, excepting the areas described beyond as Huronian.

A small part of the Canada Laurentian has been announced as probably unconformable on the rest; and Logan has suggested for it the name of the Upper Laurentian, or Labrador beds. One area covers part of Montcalm and Terre-bonne; another lies west of Lake St. John; others northeast of Montmorency Falls, and near St. Paul's Bay.

Kinds of Rocks. — The rocks, with few exceptions, are metamorphic or crystalline rocks. They include granite and gneiss and some mica schist; also, very prominently, rocks of the hornblende (and pyroxene) series, as syenyte, hornblendic gneiss, and other kinds; also extensive beds of crystalline limestone. Besides these, there are quartzyte and conglomerate. The lime-and-soda feldspar called labradorite — often characterized by a beautiful play of colors — is common in Archæan terranes, forming, with a lamellar mineral related to pyroxene or hornblende, the rock hypersthenyte.

Chrysolite, a silicate of magnesia and iron, is a constituent of some hypersthenyte. Apatite (phosphate of lime) is a common mineral, and is often found in grains or crystals in the iron ores.

Abundance of iron-bearing minerals is a striking characteristic of the Archæan rocks. It is the cause of the frequent reddish color of the feldspar of the granytic rocks. It is apparent in the prevalence of rocks of the hornblendic series, the black variety of hornblende and pyroxene, present in them, containing much iron. It is especially manifested in the existence of immense beds of iron ore, which consist either of magnetite (Fe^3O^4), or of hematite (Fe^2O^3) or of titanic iron (the last differing from the others in having part of the iron replaced by titanium). The beds are occasionally one or more hundred feet thick, as in the Missouri Iron Mountain, the Adirondack region of New York, the Marquette region of the northern peninsula of

Michigan, in Sweden, etc; and they occur interstratified with the Archæan schists and quartzyte. They far exceed in thickness the iron ore beds of later ages. In Sussex County, N. J., near Franklin and Stirling, the ore of the great bed is a zinc-iron ore called franklinite.

Another very common material is *graphite* (or plumbago), a form of carbon. It occurs disseminated through the rocks, especially the limestones, constituting 20 to 30 per cent. of some layers (which therefore are worked for the graphite.) It is often met with in scales through the iron ores; also in veins which afford it in a purer state, and often crystallized.

There are, in addition, dioryte, epidotic gneiss and schist; massive hornblende rock and hornblende schist; garnet-euphotide (eclogyte) and a feldspar-euphotide; soapstone (rensselaerite, p. 72); serpentine, ophiolytes or verd-antique marble of different varieties.

Part of the feldspar related to labradorite has the composition of andesite or anorthite; and oligoclase exists in the Swedish rocks. Part of the hypersthenyte contains ordinary hornblende instead of hypersthene, and some kinds, mica or epidote. Good localities for the opalescent labradorite are the streams of the Adirondack, — especially, says Professor Emmons, the beaches of East River; also Avalanche Lake, near the foot of the great slide from Mount McMartin.

The potstone or soapstone called *rensselaerite* covers considerable areas in the towns of Fowler, Canton, Edwards, Hermon, etc., St. Lawrence County, and at Grenville, in Canada, and is cut into slabs for tables, chimney-pieces, and furnace-linings, or made into inkstands. The *parophyte* or aluminous potstone of Diana, Lewis County, N. Y., is used for inkstands, etc.

Beautiful red and green porphyry and a buhrstone are found at Grenville, Canada.

Among the minerals of the Laurentian rocks, the most common are — Orthoclase, scapolite, nephelite, pyroxene, hornblende, epidote, mica of different kinds, garnet, tourmaline, zircon, idocrase, sphene, wollastonite, chrondrodite, among silicates; rutile, hematite, magnetite, franklinite, titanic iron, corundum, among oxyds; apatite, a phosphate; graphite. The apatite is in some places abundant, and is mined for fertilizing soils. The franklinite of New Jersey is associated with zincite or oxyd of zinc, and willemite, a silicate of zinc. Iolite is a common mineral in Bavaria.

Lead veins occur in Canada, and near Rossie, New York, affording galenite, blende, and iron and copper pyrites, with calcite and some barite and fluor; but Hunt concludes, from the fact that the vein at Ramsay, Canada, traverses also Silurian rocks, and the latter contain similar veins elsewhere, that all probably belong to a later date, instead of being Archæan.

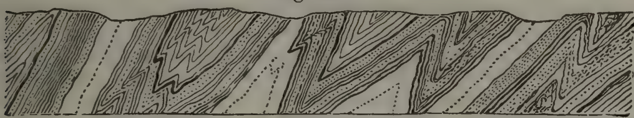
Arrangement of the rocks. — Although the Archæan rocks are mostly crystalline, they follow one another in various alternations, like the sedimentary beds of later date. In the sections which have been given, there are alternations of granite, gneiss, schists, limestone, etc.; and the dip and strike may be studied in the same manner as in the case of any tilted sandstones or shales. The following sections represent other examples; and in them there are beds of iron-ore, fifty feet and upward in thickness, which are banded with siliceous layers and chlorite schist, showing thereby a distinctly stratified character. Where most flexed or folded, there is still a distinction of layers; and it is owing to this fact that the rocks may be described as folded; for folds can be identified only where the

rocks are in sheets. This grand fact is, then, evident, — that the Archæan rocks are stratified, as much as the rocks of any later age.

In the series in the region of Ottawa, there are three great limestone strata, separated by gneissoid rocks, in all not less than 3,500 feet in thickness. The upper of these limestones is about 1,500 feet thick; but nearly half consists of intercalated layers of gneiss, and the limestone of each stratum is often associated with, or passes into, rocks consisting largely of pyroxene or hornblende; and these portions often abound in minerals, the most common of which are graphite, orthoclase, mica, scapolite, wollastonite, sphene, serpentine.

The following section by Logan (real in its general truths, although partly ideal) exhibits well the fact and condition of the stratification. It presents to view a stratum

Fig. 207.



of (*a*) white granular or crystalline limestone, many times folded, and interstratified with gneiss and quartz rock (*b*); and the limestone has been traced over the same region (Grenville and adjacent country, Canada), in linear and curving bands corresponding to a series of folds.

The following figures represent iron-ore beds alternating with other strata. In

Fig. 208.

Fig. 209.

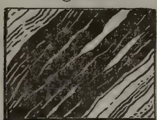
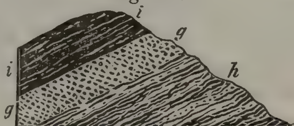


Fig. 210.

Fig. 208 (from the Michigan region, Foster and Whitney), the iron-ore, in extensive beds (*i*, *i*), occurs between chlorite slate (*a*, *a*) and dioryte (*b*); and the iron-ore in *i* is banded with jasper. In Figs. 209 and 210 (Essex County, N. Y., Emmons), the iron-ore, in beds several yards wide, is associated with gneiss and quartz rock, and is interlaminated with quartz, the whole dipping together in a common direction, like beds of sandstone, shale and iron-ore, in many regions of sedimentary rocks. At the Adirondack mines, in Essex County, N. Y., one bed, according to Emmons, is 150 feet thick.

Fig. 211.



In Fig. 211 (Penokie Range, south of Lake Superior, C. Whittlesey), *h* is hornblende rock and slaty quartz; *g*, quartzyte, 30 feet thick; *i*, a bed of iron-ore, 25 to 50 feet thick.

In the Missouri region, at Pilot Knob, — a hill 662 feet high above its base, — there is a bed of hematite, 46 feet thick, overlaid by 140 feet of porphyry-conglomerate, and underlaid by a red jaspery porphyry and other porphyritic rocks; and the ore-bed is divided into two parts by a layer of slate ten inches to three feet thick. The pebbles of the porphyry-conglomerate are cemented by iron-ore. The rocks of the region also include granyte. (Pumpelly.) When the region was first visited, the surface of the hill was covered mostly with huge blocks of the ore.

The iron-ore, which is found so very abundantly in each of these regions, is partly

magnetic and partly specular ore, or hematite, — that of Lake Superior and Missouri mostly the latter, and that of New York mainly the former.

In western North Carolina, great beds of magnetite, and also of hematite and titanic iron, occur between layers of hornblende schist and mica schist, with intercalated layers at times of jaspery quartz; one of the beds is over 300 yards thick (Genth).

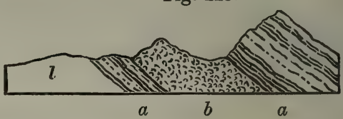
In Canada, at Bay St. Paul's, there is a bed of titanic iron, 90 feet wide, exposed for 200 or 300 feet, occurring in syenyte, with rutile or oxyd of titanium. The ore does not differ from ordinary specular iron in appearance; but the powder is not red.

In Sweden and Norway, the iron-ores are interstratified in the same manner with crystalline rocks, — mainly gneiss, hornblende rocks, chlorite slate, clay slate, quartzyte and granular limestone, with which they are more or less laminated. At Dannemora, the stratum containing iron is 600 feet in width; and it occurs with granular limestone, chlorite slate and gneiss. At Utö, Sweden, red, jaspery quartz bands the ore, in the same way as in Michigan; the ore — hematite mixed with magnetite — occurs in mica schist and quartzyte, in an irregularly-shaped mass, about 120 feet in its widest part. At Gellivara there is an iron mountain three or four miles long and one and a half wide, consisting mostly of magnetite, with some hematite. In each of these regions the beds dip with the enclosing rock, — showing that all have had a common history.

In the annexed sections (St. Lawrence County, N. Y., Emmons), granular limestone is represented in connection with granite and other rocks. In Fig. 212, *l* is limestone, without any appearance of stratification; and the containing rock is granite. In Fig. 213, *a a* are gneiss, *b* steatyte, *l* unstratified limestone. Although *a* and *b* are not

Fig. 212.

Fig. 213.



evenly stratified, yet they are sufficiently so to show that the limestone, while it has lost its division into layers in the crystallizing process, is probably a conformable stratum.

The quartzyte of Sauk County, Wisconsin, is referred to the Archæan (Irving).

The *order of stratification* among the Archæan rocks is as various as among the rocks of other ages. As sandstones, shales, argillaceous sandstones, conglomerates, follow one another in any succession, so granite or gneiss may lie between layers of slate or schist, and quartz rock or limestone may have any place in the series. It is common, however, to find the different hornblendic rocks associated together; and both these and the chloritic often abound in the iron-regions, since hornblende and chlorite are ferriferous minerals. The association of pyroxene and hornblendic rocks with the limestones has been mentioned above.

Original condition of the Laurentian beds. — The alternations of hornblendic and other schists with quartzyte, limestone, gneiss, and the other rocks, prove that all were once sedimentary beds, — beds formed by the action of moving water, like the sandstones, argillaceous beds, and limestones of later times. They have no resemblance to lavas or igneous ejections. The schists graduate into true slates, and the quartzytes into unmistakable sandstones and conglomerates; so that

there is direct proof in the gradations as well as in the arrangement in alternating layers, that all the schists and limestone rocks are parts of one series of sedimentary beds, which by some process have been hardened and crystallized. Moreover, there is as direct a passage from the gneiss to the gneissoid granite, and thence to true granyte and syenyte; so that even the most highly crystalline rocks cannot, as a general thing, if at all, be separated from this series. These Laurentian rocks, therefore, are made out of the ruins of older Laurentian, or of still older Archæan rocks, — that is, of the sands, clays and stones made and distributed by the ocean, as it washed over the earliest-formed crust of the globe. The loose material transported by the currents and waves was piled into layers, as in the following ages, and vast accumulations were formed; for no one estimates the thickness of the recognized Laurentian beds as below thirty thousand feet. Limestone strata occurred among the alternations; and argillaceous iron-ores, like the beds of the Coal-measures, though vastly more extensive; and beds of earthy ores of zinc were a part of the formations in the deposits.

The beds, moreover, were spread out horizontally, or nearly so; for this is the usual condition with sediments and limestones, when first accumulated. The original condition, then, of the rocks was the same as that of ordinary modern sediments — in horizontal beds and strata.

Disturbances and Foldings. — But, from the sections and descriptions on the preceding pages, it is apparent that *horizontal* Laurentian rocks are now exceedingly uncommon. The whole series has been upturned and flexed, broken and displaced, until little, if any, of it remains as it was when accumulated.

This upturning, moreover, is not confined to small areas, nor has it been done in patchwork-style; for regions of vast extent have undergone in common a profound heaving and displacement. This community of action or history is evident in the fact that the rocks have nearly a common *strike* over wide regions, — the strike being at right angles, or nearly so, to the action of the force causing the uplift.

The strike in the New York, Canada, Michigan, and Lake Superior Archæan is generally northeastward, or nearly parallel to the course of the Appalachians and Green Mountains, but varies to north, and also to east.

In the New York region, according to Emmons, the course of the line of limestone from Johnsburg to Port Henry, on Lake Champlain, is nearly *northeast;* that of another, along by Rossie (between Black Lake and Pitcairn, and from Theresa nearly to Lisbon and Madrid), *north-northeast;* another, parallel to this, extends from Antwerp to Fowler and Edwards. These outcrops of limestone follow the line of strike. The *dip* varies from 10° to 90°, either side of the perpendicular. The iron-ore beds have the same strike; for all together constitute one system.

In Canada, the limestone ranges of the township of Grenville have a course, ac-

cording to Logan, between northeast and north-northeast, and mostly the latter; and the strike of the gneiss and schists has the same general course.

The usual strike of the Archæan rocks of Scandinavia is also to the northeastward, — a fact to be expected where this is the general trend of the mountain range.

The beds were laid down as sediments over immense continental areas; and then followed an epoch of uplift, when the horizontal layers were pressed into folds and displaced, on the grand scale explained. Many such periods of uplift may have previously occurred. But it is evident that uplifting and disturbance were not the prevailing condition of Laurentian times, any more than they were of later ages. This is proved by the conformability of the various beds to one another in this system of foldings. An age of comparative quiet, allowing of vast accumulations of horizontal strata, even to a thickness of 30,000 feet, must have preceded the epoch of disturbance.

In these primeval times, the ocean worked almost alone at rock-making, without the aid of great rivers to wear off and bring material for its use, as in the later ages; and consequently rock-making went forward then with extreme slowness. It is obvious, therefore, that the period of comparative quiet, in which the 30,000 feet of rock were deposited, was long. It had the aid of an excessive proportion of carbonic acid in the atmosphere to be carried down with the rains, so that this most efficient of all agents in rock-destruction (p. 705) must have worked with an energy unknown in later time. (Hunt.)

Alterations: Solidification and Crystallization. — Besides the displacements, there was an almost universal crystallization of the old sedimentary beds and limestones; and now, in place of the sands and clays and earthy limestone layers, the rocks, through this metamorphism, are granite, gneiss, syenyte, granular limestone, etc. The once massive and earthy limestones now contain in many places crystals of mica, scapolite, apatite, spinel, etc.; and the limestone itself is in part a white or variegated architectural marble. The argillaceous iron-ore has become the bright hematite or magnetite; and it is banded by, or alternates with, schist and quartz, etc., which were once accompanying clay and sand layers. The franklinite (zinc-iron ore) and its associated ores of zinc, often in regular crystallizations, were made from the stratified beds containing impure zinc and iron ores, and were in part limestone strata, like those which afford such earthy ores in Belgium and Carinthia, and near Bethlehem in Pennsylvania.

Some of the Archæan rocks have experienced a second or third alteration during the later ages. The potstone or rensselaerite, gieseckite, and part of the serpentine, with some of the associated minerals, are among these later products. The rensselaerite has been observed under the crystalline form of pyroxene, showing that in part, at least, it has been made out of pyroxene; and the gieseckite exists under the crys-

talline form of nephelite, evincing that it was made out of preëxisting nephelite crystals, like the gieseckite of Greenland, which it resembles in aspect and composition. Another species, loganite, has the forms of pyroxene. Other evidences of alteration subsequent to the original crystallization are the rounded crystals of quartz and apatite of Gouverneur, and the soft spinels of St. Lawrence County, called houghite or hydrotalcite. In view of the remoteness of the Archæan era, and also of the chemical powers of water, especially when charged with heat and therefore with alkalies and silica, such changes are not a source of wonder.

Igneous or eruptive rocks. — There are few examples of dikes of igneous rocks, through the Laurentian of Canada; and these are mostly confined to the county of Grenville. The dikes there are of four different periods of eruption. The oldest, as Hunt observes, consist of greenish-gray dolerуte. These are intersected by dikes of red syenyte, in part granitic; these again by others of a quartz-bearing porphyry (orthophyre), greenish, reddish or black, with the crystals of feldspar red; and, finally, there is a fourth series, consisting of grayish-black dolerуte, containing some mica, sphene and titanic iron, besides occasionally large crystals of augite. These last resemble the dikes intersecting the Silurian, and are regarded as of Silurian eruption. The others occur where the Laurentian is overlaid by the lowest Silurian, and hence must be of pre-Silurian age. (Logan's Rep. 1863, p. 652.)

II. Life.

1. Plants. — No distinct remains of plants have been observed.

The occurrence of graphite in the rocks, and its making 20 per cent. of some layers, is strong evidence that plants of some kind, if not also animals, were abundant. For graphite is carbon, one of the constituents of wood and animal matters; and mineral coal, whose vegetable origin is beyond question, has been observed, in the Carboniferous rocks of Rhode Island, changed to graphite; and even coal-plants, as ferns, occur at St. John, New Brunswick, in the state of graphite. Further, the amount of graphite in the Laurentian rocks is enormous. Dawson observes (taking his facts from Logan) that it is scarcely an exaggeration to maintain that the quantity of carbon in the Laurentian is equal to that in similar areas of the Carboniferous system. Still the graphite may be of mineral origin.

In Europe, graphite occurs in the Archæan rocks of Bavaria; anthracite has been observed in the iron-bearing rocks of this age at Arendal, Norway; and carbonaceous (partly anthracite) and bituminous substances are distributed through layers of Archæan gneiss and mica schist at Nullaberg, in Wermland, Sweden, constituting 5 to 10 per cent: facts pointing clearly to the existence of life before the close of this era. *Animal* life, as Hunt observes, may have afforded part of the carbonaceous material, and, perhaps, as large a part as vegetable life.

The plants must have been the lowest of Cryptogams or *flowerless* species, and mainly, at least, *marine Algæ* or *Sea-weeds;* for the Primordial beds next succeeding contain remains of nothing higher. This argument from the Primordial excludes all Mosses and the ordinary terrestrial plants; but not necessarily Lichens, since these grow in dry places, and could not have contributed to marine deposits if they had existed. It is hence possible that, besides sea-weeds in the water,

there were *Lichens* over the bare rocks. The easily destructible *Fungi* may also have lived in damp places.

2. Animals. — Animals of the lowest division of animal life, that of Rhizopods among Protozoans, were probably abundant. The existence of strata of limestone, alternating with metamorphic schists, affords a strong presumption in favor of the existence of some living species, since all newer limestones of much extent intercalated among stratified rocks have been made mainly of the calcareous relics of such species; and the Rhizopods are those animals which should have first appeared. These limestones may, however, have proceeded from the secretions of these plants, kinds related to Nullipores and Coccoliths (pp. 60, 135). The *apatite* (calcium phosphate), which is abundant in some Archæan rocks, especially the limestones, has been supposed to have come from animal secretions (pp. 60, 61); but it may be a deposit from the sea-water, or from preëxisting rocks.

The existence of Rhizopods is believed by many to have been demonstrated by the discovery of their fossils in serpentine associated with the limestone, and later in the limestone itself. Dawson, who made the earliest investigations of them, named the species (one found in Canada) *Eozoon Canadense.* It is pronounced a kind of coral-making Rhizopod. The coral-like masses attributed to them are sometimes several feet in diameter.

Fig. 214.

Fig. 214 represents, natural size, a section of a specimen of this fossil, from Grenville. The white bands are the calcareous layers supposed to have been secreted by a layer of the Rhizopods, while the dark bands correspond in position to the layer of Rhizopods, and are made up of mineral material (serpentine generally, sometimes pyroxene, loganite, etc., according to Hunt) that, after the death of the animals, filled the cells. Dilute muriatic acid removes the limestone, and opens the rest to examination.

The specimens of *Eozoon* were first supposed to be **Polyp-corals** (Logan's Rep. Geol. Can., 1863, p. 48), and afterward announced as Rhizopods by Dr. Dawson (Logan's Rep. Geol. Canada, for 1866; Am. J. Sci., II. xxxvii. 272, 431, 1864, xl. 344, 1865).

They occur in the third or Grenville stratum of limestone of the Laurentian, near Grenville, and in the Petite Nation Seignory; also in Burgess (where the calcareous part is dolomite according to Hunt), and at the Grand Calumet, in a limestone whose place in the series is not determined; but whether or not anywhere in the first and second limestones is not known; also in Nova Scotia, in New Brunswick, and in Massachusetts, at Newburyport, Chelmsford and Bolton, where the spaces are filled

with serpentine. *Eozoon* has also been observed in Archæan rocks in Bavaria (named *E. Bavaricum*), in Saxony, Bohemia, Hungary, and at Pargas in Finland.

Profs. Wm. King and J. H. Rowney, of Dublin, hold that *Eozoon* is of *mineral* and not of animal origin (Proc. Roy. Irish Acad. for 1869 and 1871); and others have urged the same opinion. Doubts are excited by the fact that it resembles in structure forms that are of mineral origin; by the unequal thickness of the calcareous layers and the interspaces; and by the fact that serpentine of later formations has afforded similar forms. H. J. Carter, by his research, is led to reject it; Dr. Carpenter, by his, to sustain it.

Forms resembling Annelid tubes have been stated by Dr. Fritsch to occur in the Laurentian of Bohemia; and Dr. Dawson, from some obscure indications, has suggested the "possible existence" of sea-worms or Annelids in the Canada Laurentian. Whatever may be the final decision with regard to *Eozoon*, there can be little doubt that Rhizopods existed in Archæan time.

2. HURONIAN PERIOD.

Geographical Distribution, and Rocks. — The rocks first distinguished as Huronian lie over a region on the north coast of Lake Huron, extending from a point a few miles west of French River nearly to Sault Ste. Marie. The width is undetermined, but probably it does not exceed ten or fifteen miles. They lie unconformably upon the Laurentian rocks, showing that they are of subsequent origin; but they contain no fossils to fix precisely their age. Other smaller areas occur on the north shore of Lake Superior.

The rocks of the Lake Huron region include greenish siliceous slates and conglomerates; quartzytes; layers of jasper and chert; hard quartz and jasper conglomerates; thin layers of grayish or blueish limestone; and also beds of dioryte, which in some places graduate into syenyte, and in others contain epidote. The strata of quartzyte and conglomerates are from 1,000 to 2,500 feet thick. The latter contain stones (some a foot in diameter) that were derived from the Laurentian. Some of the sandstone layers are ripple-marked. The limestones contain none of the minerals common in this rock in the Laurentian.

The strata are much intersected by dikes of dioryte; and it has been questioned whether the beds of dioryte were not injected beds. There are also large numbers of veins bearing copper ores (sulphids chiefly), which intersect the dikes of dioryte, and are therefore the later in origin.

Besides the above-mentioned regions of Huronian rocks, there are others which are referred to this period mainly on lithological grounds, — chloritic rocks, dioryte, felsitic (porphyroid) rocks and epidotic rocks being regarded as especially characteristic of the Huronian.

Of these are: (1) In Michigan, the large area, south of Lake Superior, in which lie the immense iron-ore beds of Marquette, already mentioned (p. 151). The rocks are in part dioryte, chlorite schist, beds of jasper and chert. As it is not certain that such an association of rocks may not have been formed in other eras, and even in the Laurentian, the evidence as to age is far from conclusive. The extent of the beds of iron-ore affords some reason for believing, as shown by Whitney, that they are true Laurentian.

The iron-ore, unlike that of northern New York, is specular iron-ore (Fe^2O^3). But it contains in many places octahedral crystals, which appear to indicate that it was once *magnetic* iron-ore, and therefore that originally the ore of the two regions was alike. H. Credner refers part of the region to the Laurentian, but retains the Marquette portion in the Huronian. He states, that he observed an example of unconformability between the two systems of beds. They are also stated to be unconformable by Brooks and Pumpelly.

(2.) Other regions of rocks supposed to be Huronian occur in Newfoundland, New Brunswick and some parts of New England; in most cases they have been determined only by the valueless test — the nature of the rocks. Credner refers to the Huronian, with no better reason, a range of rocks along the whole course of the Appalachians, from Canada to South Carolina; and he so calls certain auriferous rocks of Montgomery County, North Carolina, which Emmons refers to the Taconic system, including hydromica schist, quartzytes, itacolumyte or flexible sandstone, etc. Emmons found in one of the beds a fossil-like form, which he pronounced a silicified coral and named *Palæotrochis* (Am. Jour. Sci., II. xxii. 389); but, according to Hall and Marsh, it is probably only a concretion.

As the original Huronian has no fossils, there is no basis for a satisfactory determination of its equivalents. It is quite possible that it is Cambrian or Primordial.

3. GENERAL CONCLUSIONS.

Relations of the North American Archæan areas to the Continent. — On the map, p. 149, the striking fact is shown that the great northern V-shaped Archæan area of the continent has (1) its *longer* arm, B B, parallel approximately to the Rocky Mountain chain and the Pacific border; and (2) its shorter, C C, parallel to the smaller Appalachian chain and the Atlantic border. Further: Of the other ranges of Archæan lands, (1) there is one near the Atlantic border, in Newfoundland, Nova Scotia, and New England; (2) another along the eastern side of the Appalachian chain; (3) two or more, of great length, along the Rocky Mountain chain; and (4) others, not included in the above, lie in ranges parallel to these main courses. Moreover, the Archæan rocks of these regions were upturned and crystallized before the Silurian age, and probably at two or more different epochs; and some, if not all, were thus early raised into ridges, standing not far below the water's surface, if not above it.

Hence, in the very inception of the continent, not only was its general topography foreshadowed, but its main mountain chains appear to have been begun, and its great intermediate basins to have been defined — the basin of New England and New Brunswick on the east; that between the Appalachians and the Rocky Mountains over the great interior; that of Hudson's Bay between the arms of the northern V. The evolution of the grand structure-lines of the continent was hence early commenced, and the system thus initiated was the system to the end. Here is one strong reason for concluding that the continents have always been continents; that, while portions may have at times been submerged some thousands of feet, the continents

have never changed places with the oceans. Tracing out the development of the American continent, from these Archæan beginnings, is one of the main purposes of geological history.

Source of the material of later fragmental rocks. — The Archæan rocks, and rocks made from them, are the main source of the material of subsequent non-calcareous fragmental rocks. Volcanic eruptions have added a little to the supply; chemical depositions also a little; and the siliceous secretions of the lowest orders of plants and animals have contributed silica to some extent; but all these sources are small compared with those of the Archæan terranes. From the fact pointed out, that these most ancient of rocks were distributed, as the Silurian era opened, in insular areas all along the Atlantic border — from Labrador, through New England, southwestward (and other areas may have existed, which are now at shallow depths under other rocks or the sea-border) — it is seen, as Hunt has urged, that they were well situated for supplying, through the help of the ocean, mud, sand and gravel, for the deposits that were in progress as the next era opened. And their contributions have continued ever since to be used in rock making, both directly and through the strata which had been made from them.

Life. — The earliest representatives of animal life on the earth had no special organs, either of *sense;* of *motion*, excepting minute hairs, or hair-like processes; or of *nutrition*, beyond, at the best, a mouth and a stomach. It was life in its simplest or most elemental condition — systemless life — since neither of the four grand systems of the animal kingdom was distinctly indicated. Such was the beginning

Indications of plants occur in earlier Archæan beds than those of animals; yet the absence of animal remains may be owing to the metamorphism of the rocks. That plants preceded animal life on the globe is altogether probable, because they may live and reproduce in hotter waters; and, therefore, a temperature admitting of the existence of plants would have been reached, in the progressing refrigeration, before that favorable to animal life. The fact, also, that animals need plants for food (page 115), affords a strong presumption in favor of the view that plants were first in existence.

II. PALEOZOIC TIME.

I. AGE OF INVERTEBRATES, OR SILURIAN AGE.

The term Silurian was first applied to the rocks of the Silurian age by Murchison. It is derived from the ancient name Silures, the designation of a tribe inhabiting a portion of England and Wales where the rocks abound.

The subdivisions of the Silurian are not only widely different on two continents, as America and Europe, but also on different parts of the same continent. In American geological history, it has been found most convenient to recognize in the main that subdivision into periods and epochs which is derived from the succession of rocks in the State of New York, where most of the strata are well displayed and have been carefully studied.

Some standard for the division of time must be adopted; and, whatever that standard, it is afterward easy to compare with it, and bring into parallelism, the successive strata, or events, of other regions. The State of New York lies on the northeastern border of the great interior, — a vast region stretching southward and westward from the Appalachians to the Rocky Mountains, and beyond the head-waters of the Mississippi to the Arctic Ocean, over which there were many common changes; and, owing apparently to this situation on the north against the Archæan, and near the head of the Appalachian range, there are indicated a greater number of subordinate subdivisions in the rocks, or of epochs in time, than are recognized to the west. It is, therefore, a more detailed indicator than other regions, of the great series of changes and epochs in the Paleozoic era.

On pages 375 to 379, sections are presented of the Paleozoic strata in different parts of the United States; and, by means of them, the diversities between the regions may be studied. The general truth, above stated, is well exhibited, that the geological structure of the great Interior basin is more simple than that of New York and the Appalachian region.

The order of succession in the Silurian periods and rocks is shown in the section on page 142 (Fig. 201). The numbers affixed to the subdivisions of the section are used for the same formations throughout the work.

The Silurian age is divided into the *Lower* Silurian and *Upper* Silurian. In North America, the transition in the rocks and life of the two eras is comparatively abrupt. In Great Britain, the two are generally unconformable in stratification ; but as regards life there is a gradual transition between them. In Bohemia, there is no break in the rocks, but a somewhat abrupt change in the life. Thus, even the grander divisions in Geological history are not set forth alike in all countries ; each great region has carried forward independently its making of rocks, and had often its independent disturbances.

SUBDIVISIONS OF THE SILURIAN.

A. LOWER SILURIAN.

I. PRIMORDIAL OR CAMBRIAN PERIOD (2).

1. ACADIAN EPOCH (2 *a*). Shale and sandstone at St. John, New Brunswick, the St. John group of Matthew and Logan, the Acadian group of Dawson; beds at St. Johns and elsewhere, in Newfoundland; clay-slate and siliceous slate of Braintree, Mass.; Ocoee conglomerate and slates of East Tennessee and North Carolina.

2. POTSDAM EPOCH (2 *b*). Sandstone of Potsdam and other places in northern and northeastern New York, western Vermont and Canada; sandstone and limestone of Troy, N. Y.; slate and limestone of northwestern Vermont, including the Georgia shales; limestone and sandstone of shores of the Straits of Belle Isle; Chilhowee sandstone of East Tennessee; sandstone with some limestone in Wisconsin and Minnesota.

In Great Britain, the Cambrian, including beds in the Longmynd, in North Wales, the Harlech beds in Pembrokeshire, and the overlying Menevian beds, and also, higher in the series but conformable, the Lingula flags. In Bohemia, Barrande's Stage C, and perhaps his B, or part of it. In Sweden, Angelin's A and B, the Alum slate and Fucoidal sandstone.

II. CANADIAN PERIOD (3).

1. CALCIFEROUS EPOCH (3 *a*). Calciferous sandrock in New York. Lower Magnesian limestone of the Mississippi valley; St. Peters sandstone of Wisconsin and Illinois; Knox sandstone, East Tennessee; thick limestones (part of the so called Quebec group) of Newfoundland.

2. QUEBEC EPOCH (3 *b*). Canada, near Quebec; shales, limestones, and sandstones, Newfoundland. Part of the Knox group, Tennessee.

3. CHAZY EPOCH (3 *c*). Chazy limestone of New York, Canada, etc. Part of the crystalline limestone of the Green Mountains in Vermont and to the south.

Tremadoc slates of North Wales; Skiddaw slates of northern England; Arenig or Stiper stones group (the Lower Llandeilo of Murchison). Angelin's group B C in Sweden. The Pleta of Russia, according to Billings, and the Ungulite grit of Pander.

III. TRENTON PERIOD (4).

1. TRENTON EPOCH (4 *a*): (1) Birdseye limestone, (2) Black River limestone, (3) Trenton limestone; Galena limestone of Illinois, etc.; Lebanon limestone of Middle Tennessee.

In Great Britain, Llandeilo group. In Bohemia, Barrande's formation D. In Sweden, Angelin's C, Orthoceratite limestone.

2. Utica Epoch (4 *b*). Utica shale.

3. Hudson River Epoch (4 *c*). Hudson River shales and slates, Lorraine shales, of New York; the larger part of the limestone about Cincinnati; Nashville group of Tennessee.

In Great Britain, Bala limestone and Caradoc sandstone; upper part of Llandeilo flags; Lower Llandovery sandstone. In Bohemia, Barrande's formation D[1] In Sweden, Graptolitic slate; Angelin's Region D. In Russia, the Wesenberg Lyckholm, and Bornholm groups.

B. UPPER SILURIAN.

I. Niagara Period (5).

1. Medina Epoch (5 *a*): Oneida conglomerate and Medina sandstone.

2. Clinton Epoch (5 *b*): Clinton group.

3. Niagara Epoch (5 *c*): Niagara shale and limestone; Guelph limestone.

In Great Britain, the Upper Llandovery or May Hill sandstone has been referred to the Clinton and Medina, and the Wenlock shale and limestone to the Niagara. In Sweden, part of Region E of Angelin, and, in Bohemia, Stage E of Barrande are probably equivalents of the Medina, Clinton, and Niagara. The Pentamerus group of Esthland and Livland in Russia, and the Lower Malmö of Norway are referred to the Medina and Clinton, and the middle Malmö to the Niagara.

II. Salina Period (6). Onondaga Salt group.

III. Lower Helderberg Period (7).

Lower Helderberg limestones, including, in New York, (1) the Water-lime group; (2) the Lower Pentamerus limestone; (3) the Delthyris shaly limestone; (4) the Upper Pentamerus limestone.

IV. Oriskany Period (8). — Oriskany sandstone.

In Great Britain, the equivalents of the Lower Helderberg and Oriskany groups are approximately the Ludlow beds, including the Lower Ludlow rock, the Aymestry limestone, the Upper Ludlow rock and the Tilestones. In Norway, Upper Malmö limestones and schists. Part of E of Angelin, in Gothland, Sweden, the Coral limestone. In Bohemia, Barrande's formations E to H, consisting of schists, part graptolitic, and limestones, are referred to the Upper Silurian.

Explanation of the Section and Geological Map.

The annexed map of New York and a part of Canada exhibits the surface-rocks of the region. As is shown in the section, p. 166, the strata of the Silurian and Devonian outcrop in succession, on going from the Archæan (No. 1) southward. The numbers on the areas render easy a comparison with the section and with the tables beyond. The Silurian strata are lined *horizontally*; the Devonian, *vertically*; and the Subcarboniferous beds, which appear at the southern margin of New York State (No. 13), are cross-lined. The area very coarsely cross-lined horizontally includes the Chazy and Trenton limestones; the Chazy (3 *c*) is separated from the Trenton by a dotted line.

The area 5 (Niagara period) is divided into *a*, *b*, *c*, corresponding to 5 *a*, 5 *b*, 5 *c*, in the preceding table. Other areas are similarly divided. The areas of Nos. 7 and 8 in

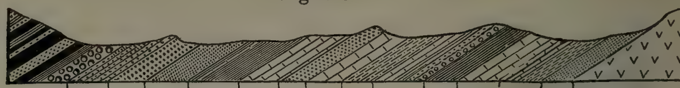
Fig. 215.

Geological Map of New York and Canada.

the series (the Lower Helderberg and the Oriskany) are not distinguished on the map from No. 9.

Fig. 216 is an ideal section of the rocks of New York, along a line running *southwestward* from the Archæan on the north across the State

Fig. 216.



to Pennsylvania. It shows the relative positions of the successive strata, — bringing out to view the fact that the areas on the preceding map are only the outcrops of the successive formations. This is all the section is intended to teach; for the uniformity of dip and its amount are very much exaggerated, and the relative thickness is disregarded.

A. LOWER SILURIAN.

I. PRIMORDIAL PERIOD (2).

1. American.

The Primordial or Cambrian Period in North America includes two subdivisions, distinct in their fossils, according to present knowledge.

(1.) The *Acadian Epoch;* (2.) The *Potsdam Epoch*, so named from Potsdam in northern New York, where they occur.

I. Rocks: kinds and distribution.

Primordial rocks probably cover the larger part of the continental area outside of the Archæan, as they are the beds first formed after the Archæan in the continental seas. But to a great extent they are covered by later formations. They are now exposed to view for the most part either (1) on the borders of the Archæan; or (2) in mountain regions, in which the upturnings of the rocks have brought them to the surface.

Those of the Acadian or earlier epoch have been observed on the eastern border of the continent, at St. John in New Brunswick, at Braintree near Boston, and in southeastern Newfoundland; they are shales, sandstones, and limestones.

The Potsdam beds are mostly sandstones, but are in some regions shale or slate and limestone. They outcrop along the borders of the Archæan in New York, Canada (see 2 *b*, on map, p. 165), Wisconsin,

Minnesota, and some parts of the Rocky Mountains, as well as in Labrador and Newfoundland; also along parts of the Green Mountain region, and portions of the eastern Appalachians in New Jersey, Pennsylvania, and farther south. As the Archæan rocks made the dry rocky land of the era, these beds made of sand consolidated, were in part at least the *beach* formations of the period. The bluffs of the Au Sable chasm, west of Keeseville, are of Potsdam sandstone. In northern Vermont, and beyond in Canada, there are slates of this era; and a reddish limestone, called the Winooski limestone, reaches south to Burlington, Vermont, and affords a handsome red marble.

1. ACADIAN EPOCH. — The rocks are exposed to view in a number of valleys in southern New Brunswick, and especially at St. John, where they were first proved to be Primordial by G. F. Matthew. The name Acadian was given to the period by Dawson. The rocks here are gray and black shales, with some sandstones, and have a thickness, allowing for a fold, of 2,000 feet. There are fossiliferous rocks of this era also in southeastern Newfoundland. In the same region, underlying beds, that have been pronounced Huronian, have afforded two fossils (see Billings, Amer. Jour. Sci., III. iii. 223). At Braintree, Mass., not far from Boston, the rock is siliceous slate and clay slate. In both regions, the beds are much upturned. The lowest beds of the Wisconsin Primordial may belong to this division, as stated beyond.

2. POTSDAM OR GEORGIA DIVISION.

a. *Eastern-Border Region.* — On the Labrador side, and parts of the Newfoundland, of the Straits of Belle Isle, there are strata of limestone, sandstones, and shales of this era. They stretch across the north peninsula of Newfoundland to Canada Bay, where the thickness, according to Murray, is 5,600 feet.

b. *New York, Vermont, and Canada.* — The rocks occur adjoining the Archæan of New York and Canada. They are here mainly hard sandstones, often gritty, sometimes pebbly (especially the lower beds), and only occasionally friable. The sandstone is generally laminated, and sometimes thinly so; and of gray, drab, yellowish, brownish and red colors. Much of it is a good building stone, as at Potsdam, Malone, Keeseville, etc. North of the Archæan, in the northwest part of Clinton County, in part of St. Lawrence County, near De Kalb, and also in Franklin County, N. Y., the conglomerate is in places 300 feet thick. The rock bears evidence of being mainly of shallow-water or beach origin.

In St. Lawrence County, N. Y., there are, according to Brooks, conformable beneath the Potsdam sandstone, strata of sandstone, metamorphic schist, limestone, and hematite iron ore (the Caledonian or Parish ore-bed included), having in all a thickness of at least 200 feet. See Amer. Jour. Sci., III. iv. 22.

The formation is represented in western Vermont by the "Red Sandrock"; the Winooski limestone extending from Addison, through Burlington to St. Albans; also, apparently over the latter, the black and gray shales or slates of Georgia, St. Albans, and Swanton (referred by Emmons to the Taconic), which continue into Missisquoi County, in Canada, lying to the west of other slates of the Quebec period. There are Primordial black shales in Bald Mountain, Greenwich, Washington County, N. Y., described as Taconic by Emmons; and shales and sandstone, with beds of limestone and limestone-conglomerate, near Troy, N. Y., recently made known by S. W. Ford (Am. Jour. Sci., III. ii. to vi.). The Troy beds, and also the Winooski marble and Georgia slates, are believed to be inferior to the Potsdam sandstone. The quartzyte of the Green Mountains of Vermont and farther south is supposed to be Potsdam sandstone.

c. *Region of the Appalachians.* — Along the Appalachian chain, the great thickness of the accumulations, and especially of the slates, is the striking peculiarity.

In New Jersey, the rocks supposed to be Potsdam are sandstone, either soft or hard;

or a red crumbling shale, as in the Green Pond Mountain Range; or a firm conglomerate. Near Flanders, a kind crumbles easily to sand.

In Pennsylvania, there are, in the *Primal* series of Rogers, 2,000 feet of lower slates, overlaid by 90 feet of sandstone, and this by 200 to 1,000 feet of upper slates (H. D. Rogers). In Virginia, there are 1,200 feet of lower slate, 300 of sandstone, and 700 of upper slates (W. B. Rogers).

In East Tennessee, J. M. Safford has described, as of this age, the "Chilhowee" sandstones and shales, several thousand feet in thickness (consisting of sandy shales, sandstones, and light gray quartzyte), resting on the Ocoee conglomerates, sandstones, and micaceous, talcose, and chloritic slates.

d. Interior Continental basin. — The sandstone rocks in New York and Canada, above mentioned, properly lie in the northeastern border of this basin.

In Wisconsin (as first announced by D. D. Owen), a broad band of the Potsdam sandstone borders the east, south, and west sides of the Archæan, south of Lake Superior, crosses the Mississippi, about the Falls of St. Croix, into Minnesota, and then stretches northward and southward, passing in the latter direction toward Iowa. The rock over the interior of Wisconsin and Minnesota is, for the most part, a very crumbling and imperfectly coherent mass of sand. It includes much *green sand* in its lower part, similar in general character to the green sand of the Cretaceous formation (Hall). It forms bluffs on the Mississippi, in Iowa, below the Upper Iowa River. This loose condition of one of the most ancient of rocks, in Wisconsin and Minnesota, shows how ineffectual are ordinary waters, even through the lapse of ages, in causing solidification. The sands are often wholly siliceous, with only 1 or 2 per cent. of impurity, and, when crumbling, make a good material for glass.

Hall (Regents' Rep. 1863) makes out three divisions of the Wisconsin beds: 1, the *lower*, containing species of *Conocoryphe* and no *Dicellocephali*; 2, the *middle*, characterized by species of *Conocoryphe*, *Dicellocephalus*, *Agraulos*, *Ptychaspis*, *Agnostus*, with the earliest *Graptolites*; and 3, an *upper*, clearly separated from the great central mass, and containing species of *Dicellocephalus*, *Triarthrella*, *Aglaspis*, *Lingula*, *Serpulites*, *Euomphalus*.

The Pictured Rocks, forming bluffs 50 to 200 feet high, on the south shore of Lake Superior, in Michigan, and the Pillared Rocks, at the west end of the lake, have been considered as of the Potsdam era.

The Potsdam beds of Texas occur in Burnet County, Texas, where they consist of sandstones covered by limestone. (B. F. Shumard.)

Beds of sandstone and conglomerate, according to Dr. Hayden, skirt the Black Hills of Dakota (lat. 43°–45° N., long. 103°–104° W.), overlying the Archæan, and containing characteristic fossils.

e. Summit and western slopes of the Rocky Mountains. — Primordial rocks occur in the Big Horn Mts., at the head of Powder River, long. 107°; as quartzytes (probably of this age), near long. 112° W., along the Wahsatch, Teton, Madison, and Gallatin ranges, resting unconformably upon the upturned Archæan gneisses and granites; also in Nevada, long. 116° W., as announced by J. D. Whitney.

The Potsdam formation is 60 to 70 feet thick in St. Lawrence County, N. Y.: in Warren and Essex Counties, 100 feet; in the St. Lawrence valley, 300 to 600 feet, or more; about 250 feet on Lake Superior; 700 feet, according to Owen, on the St. Croix, Wisconsin; 50 to 80 feet in the Black Hills, Dakota; 500 feet in Burnet County, Texas.

Markings in the rocks. — In the Acadian rocks, near St. John, N. B., the coarser layers are frequently covered with ripple-marks and shrinkage cracks, and also with scratches that appear to be the tracks of some water-animal; and, besides, there are worm-burrows. (See *Scolithus*, p. 177.) The facts, as G. F. Matthew states, are evidence that the beds are of seashore origin. The shales of Georgia,

Vermont, are in some places marked with ripples, and have the tracks of worms as well as their borings. In the Potsdam rocks of northern New York and Canada, and those of Wisconsin, there are similar evidences of littoral deposition. Ripple-marks and worm-borings are common; and, in some places in Canada, there are tracks of Crustaceans, as well as worms (p. 176). In Wisconsin, also, ripple-marks and mud-cracks occur; and, on some layers, broken shells and other appearances afford the most positive evidence of sea-beach formation. (Hall.) The beds, though of great thickness, are often diagonally laminated, showing the action of tidal currents over the bottom of a shallow sea. The Tennessee and Pennsylvania sandstones also are, in many places, penetrated by worm-borings, and covered with ripple-marks.

Economical products. — The Primordial rocks afford much good stone for building, and for the hearths of furnaces, and, in many localities, sand for glass-making. There are gold-bearing quartz veins in the Ocoee series, in Tennessee.

II. Life.

The Primordial rocks have afforded evidence only of *marine* life.

1. *Plants.* Algæ or seaweeds, of the kind called *Fucoids*, are the only forms observed. The slabs of sandstone are sometimes covered throughout with vermiform casts of what appear to be stems of this leathery kind of seaweed. Some of the fossils formerly regarded as indications of plants, are now believed to be worm-tracks or borings. But others show by their branching forms that they are true Fucoids.

2. *Animals.* The species observed are all invertebrates; they pertain to the four sub-kingdoms, PROTOZOANS, RADIATES, MOLLUSKS, and ARTICULATES.

The Radiates were represented by *Crinoids;* the Mollusks, by *Brachiopods,*[1] *Pteropods*, *Gasteropods*, and *Cephalopods;* and the Ar-

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[1] As *Brachiopods* are the most abundant fossils of the Silurian, their distinguishing characteristics and the more important genera are here mentioned, — taken principally from Davidson (Paleontographical Society publications).

1. *Animal.* — As stated on page 126, the living animal, unlike all other Mollusks, has a pair of fringed spiral arms, as shown in Figs. 222, 225; and to this the name *Brachiopod* alludes, from the Greek for *arm* and *foot.*

2. *Shell.* — The characteristics of most importance are as follow: —

a. The large valve (see Fig. 221 and others) is the ventral.

b. The form of the internal supports connected with the spiral arms varies much; and often they are wanting. The loop-form is seen in Figs. 218, 219, 220; the spiral, in Figs. 222, 225; the short process, in Fig. 227; and they are wanting in Figs. 230, 231.

c. The general form and exterior markings of the shell afford important characters; the nearly equal convexity of the two valves, or a median depression on the ventral valve, with a corresponding elevation on the dorsal, Figs. 221, 223.

d. The beak of the shell may be very large and full (Figs. 221, 238), or very small and little prominent (Figs. 229, 230); may have an aperture or *foramen* at apex (Figs. 150, 223, 224), or not.

ticulates by *Worms* and *Crustaceans*. No evidence has been yet found of the existence of Polyps (corals), among Radiates; or, in the earlier epoch, of Lamellibranchs (ordinary bivalves), among Mollusks.

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e. The hinge-line may be straight, or not; as long as the greatest breadth of the shell (221, 229, 232), or shorter (227, 228).

f. A cardinal area (hinge-area) may exist, or not; there is a large one in Fig. 221, and none in Fig. 238.

g. There may be a *deltidium*, — composed of one or two accessory pieces occupying a triangular opening under the beaks, as seen in Fig. 224. Sometimes a similar opening at the middle of the hinge is partly or entirely closed by the growth of the shell, so as to leave a triangular prominence, called a pseudo-deltidium, as in *Cyrtia*, *Streptorhynchus*, etc.

h. The markings on the inner surfaces of the valves are of special importance, and particularly the muscular impressions, usually situated near the median line, not far from the hinge: on the *dorsal* (or smaller) valve there are, in the articulated genera, two pairs (a and a' in Figs. 227, 230, 234, 236), sometimes coalescing so as to be one pair, for the attachment of the *adductor* muscle (closing the shell): one is usually in advance of the other, but in Figs. 230 and 233 they are side by side; on the *ventral* (or larger) valve, there is a single impression on the median line between two others (Figs. 228, 234); the single impression is the insertion of the *adductor* muscle (a, Figs. 228, 231, 234, 237), and the pair are the insertions of the *cardinal* muscle; the latter muscle terminates on the *dorsal* valve, usually in a small process.

Families of Brachiopods.

Terebratula Family (Figs. 150, 218–220). — Having arm-supports of the form of a loop, attached to the smaller or dorsal valve, and a foramen at the apex of the beak. Shell-structure punctate.

Spirifer Family (Figs. 221–225). — Having spiral supports, shell usually with a median fold; hinge-line commonly long and straight (sometimes short); beak large and full.

Rhynchonella Family (Figs. 226–228). — Having the arm-supports short curved processes; beak usually full, but narrow, having a foramen; shell seldom wider than high.

Orthis Family (Figs. 229–237). — Arm-supports wanting; shell rarely with a median fold; shell varying between orbicular and D-shape; beak usually very small, but sometimes produced.

Productus Family (Figs. 238–240). — Arm-supports wanting; shell without a median fold, or almost wholly so; hinge-line straight, often as long as the breadth of the shell, or nearly so, and without a cardinal area, or with only a narrow one (excepting *Strophalosia* and *Aulosteges*); surface often tubular-spinous; form usually D-shaped, with the dorsal valve very concave; beak often very large and full.

Discina Family (Figs. 243–245). — Thin and small disk-shaped shells; orbicular or ovate; a slit or foramen through the ventral valve; no articulation between the valves.

Lingula Family (Figs. 151 and 246). — Thin and small shells; orbicular or subovate; no foramen; no articulation.

Besides these, there are also the *Crania* and *Thecidium* families.

Genera of Brachiopods. — 1. *Terebratula Family.* — Genus *Terebratula*, like Figs. 150 and 218; the loop small, as in Fig. 219. Genus *Waldheimia*, the same; the loop large, Fig. 218.

Besides these genera, *Terebratulina* has the side (or "crural") processes near the base of the loop united (Fig. 220). Another genus, *Terebratella*, has the sides of the loop united at middle by a cross-piece, and this piece soldered to the shell. *Terebrirostra* has the beak extravagantly prolonged, so as to be longer than the dorsal valve. *Rensselaeria* has, instead of a loop, a peculiar hastate brachial support, projecting far

The fossils thus far obtained from the rocks of the Acadian epoch differ in species from those of the Potsdam. They include species of

within the dorsal valve. *Stricklandinia* of Billings may be the same genus, and, if so, it antedates Rensselaeria. *Centronella* seems to be intermediate between *Terebratula* and *Waldheimia*. Other genera, rarely met with, are *Trigonosemus*, *Megerlia*, *Magas*,

Figs. 218–225.

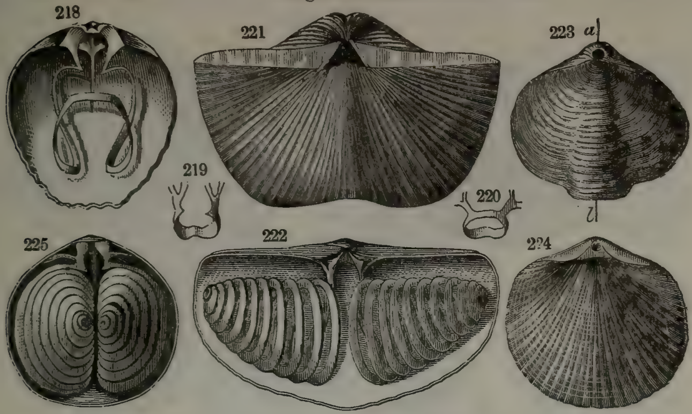

Fig. 218, Waldheimia flavescens; 219, loop of Terebratula vitrea; 220 id. Terebratulina caput-serpentis; 221, Spirifer striatus; 222, same, interior of dorsal valve; 223, Athyris concentrica; 224, 225, Atrypa reticularis, the latter dorsal valve.

Argiope, appearing first in the Cretaceous, and *Kraussia*, *Bouchardia*, and *Morrisia*, known only in recent seas, with a possible exception of the last. *Stringocephalus* is another genus, probably constituting a sub-family, occurring in the Devonian.

2. *Spirifer Family.* — The genus *Spirifer* includes the common species, having usually a long hinge-line and distinct cardinal area (Figs. 221, 222). In *Athyris* (Fig. 223), the hinge-line is much shorter, the hinge-area small or none, the beak contracted and having a small round aperture. This genus is like *Terebratula*, in its narrow form and beak without cardinal area, but has the spires of the Spirifers. *Uneites* has the beak extravagantly prolonged, and a large opening beneath it. *Cyrtia* has nearly the same extravagant prolongation of the beak, but with a large hinge-area, and a very small opening left at the top of the pseudo-deltidium. *Koninckina* is an imperfectly determined genus, resembling *Productus* in form, but differing internally.

Among other genera and subgenera of this family may be mentioned *Cyrtina*, *Retzia*, *Merista*, *Nucleospira*, *Trematospira*, *Rhynchospira*, *Charionella*, etc.

3. *Rhynchonella Family.* — The genus *Rynchonella* (Figs. 226–228) contains plump-ovoid or subtrigonal shells, usually narrower than high, and narrowing to the beak, having usually a foramen and no hinge-area; generally a U-shaped *flexure* in the anterior margin of the shell. *Pentamerus* has a much fuller and more incurved beak, and no area or deltidium, though there is a triangular opening at the middle of the hinge, which usually becomes closed in adult shells by the incurving of the beak. *Camarophoria* is a rare genus of the Carboniferous and Permian. *Porambonites*, a very plump shell of the Lower Silurian, near Rhynchonella. *Camerella* of Billings is another genus of this family, found in the Lower Silurian. *Leptocœlia* and *Eatonia* probably belong to this family. *Atrypa*, Figs. 224, 225, which is referred to this family by Woodward, on account of the arrangement of its spiral arms, narrows to the beak, where there is no hinge-area or only a small one.

Trilobites of the genus *Paradoxides* (Fig. 251), none of which are known afterward.

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4. *Orthis Family.* — In the genus *Orthis* (Figs. 235–237) the species are usually rather thin; often orbicular, at times a little wider than high; both valves in general nearly equally convex; the hinge-line usually not long, with a small cardinal area; a few species resemble a narrow Spirifer, and have a median fold and long hinge-line. *Or-*

Figs. 226–237.

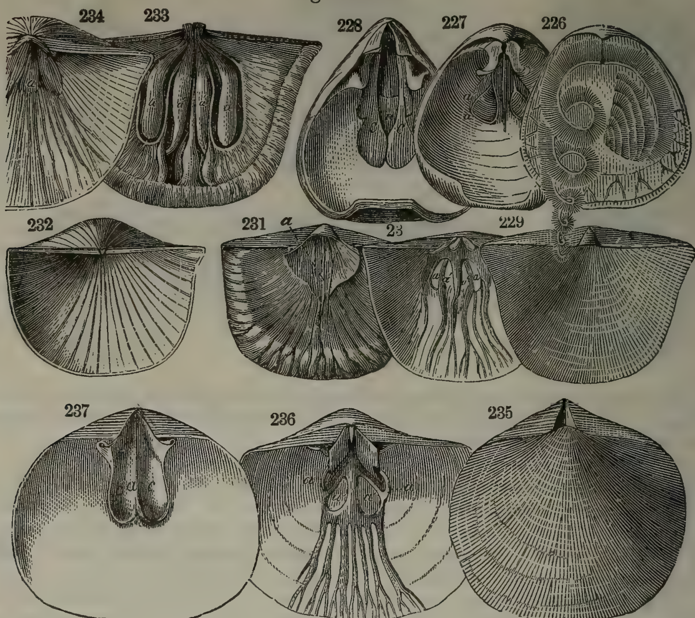

Fig. 226, Rhynchonella psittacea, showing the spiral arms of the animal; 227, id dorsal valve; 228, id. ventral; 229, Strophomena planumbona; 230, id. dorsal valve; 231, id. ventral; 232, Leptæna transversalis; 233, id. dorsal valve; 234, id. ventral; 235, Orthis striatula; 236, id. dorsal valve; 237, id. ventral.

thisina has the hinge-area very large and reversed-triangular, with a convex deltidium, and the shell subquadrate. *Strophomena* contains thin D-shaped species (Figs. 229–231), with a straight hinge-line about as long as the width of the shell, a very narrow hinge-area, the dorsal valve often very concave, with the ventral bending to correspond, and the four adductor muscular impressions in the same transverse line. *Leptæna* is similar (Figs. 232–234), but has the four muscular impressions of different character, as seen in Fig. 233, while in Strophomena they are as in Fig. 230.

5. *Productus Family.* — In the genus *Productus* (Figs. 238, 239) the beak is very full, hinge-line usually a little shorter than the width of shell; no true hinge-area, and no beak-aperture; the smaller valve concave; the surface of the shell spinous, the spines tubular; spiral arms present, but without calcareous supports. The margin of the shell is prolonged downward, often to a great length, and sometimes closes around into a tube *Chonetes* (Fig. 240) has a straight hinge-line, commonly as long as the width of the shell, the form rather thin, with the beaks not full and prominent, resembling Leptæna; smaller valve concave; hinge-edge of larger valve furnished with a few spines. *Strophalosia* is much like Productus in form and spines, but

Among the *Acadian* fossils, no remains of Crinoids have yet been found. The Brachiopods include species of *Lingulella* (Fig. 248),

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is more circular, and the shells have a hinge-area, and a regular hinge with teeth; it also differs in being attached by the beak of the ventral valve. *Aulosteges* is also similar to *Productus* in general form and spines; but there is a broad triangular hinge-area, and the beak is twisted somewhat to one side.

Figs. 238–246.

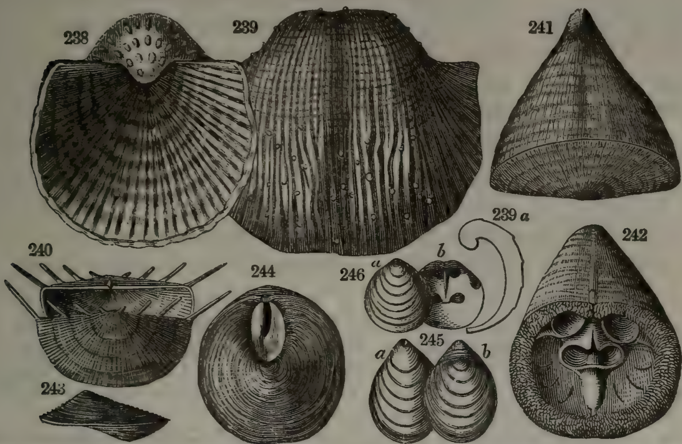

Fig. 238, Productus aculeatus, dorsal view; 239, Productus semireticulatus, ventral view; 239 *a*, section of Productus, showing the curvature of the valves; 240, Chonetes lata, opposite views; 241, Calceola sandalina; 242, Crania antiqua; 243, Discina lamellosa, side-view; 244, id. showing foramen; 245 *a*, *b*. Siphonotreta unguiculata, opposite views; 246 *a*, *b*, Obolus Appollinis.

Koninckina is like Productus in form, but has about the same relation to the Productus family as Atrypa to the Rhynchonella family.

6. *Discina Family.* — In *Discina* (Figs. 243, 244) the form is orbicular or oval, and the valves low-conical; there is a slit through the ventral valve, beginning at or near the highest point. The genus *Orbicula* is here included. *Trematis* is similar; but one valve has the umbo or prominent point marginal, or the slit reaches nearly to the margin. In *Siphonotreta* (Fig. 245), the form is ovate; the beak projects at the margin, is somewhat pointed, and has a small aperture. *Acrotreta* has the perforate valve elevated into a high oblique cone.

7. *Lingula Family.* — *Lingula* (Fig. 151) is narrower than high, and pointed at the beak; valves equal, thin. *Obolus* (Fig. 246) is rotund or rotund-ovate; valves a little unequal, the dorsal valve being the smaller and least convex, as in most Brachiopods; muscular impressions, six, — two median, two lateral, and two very near the umbos (Fig. 246 *b*), — having some approximation to the *Craniæ*. *Obolella* of Billings has still different muscular impressions, as shown in Fig. 273.

8. *Crania Family.* — The genus *Crania* has internal markings as in Fig. 242; and the shell was attached when living, by the substance of one valve to a rock or other support.

9. *Thecidium Family.* — *Thecidium* contains thick-shelled species, higher than wide, having a pointed beak, very large triangular hinge-area, and internally digitate muscular impressions; commenced in the Trias, and has a single living species.

Davidsonia is a genus of rare occurrence and undetermined relations. There is some resemblance to *Leptæna*; but it has a pair of low and faint spiral cones on the inner surface of the larger valve.

The following genera have species in the existing seas; and those having an asterisk are known only as recent. In the *Terebratula family*, the genera Terebratula, Wald-

a genus eminently characteristic of the Primordial, containing species related to the modern *Lingula;* of *Discina* (Fig. 249), disk-shaped shells; and others of *Orthis* (Fig. 250) and *Obolella.*

Figs. 247–250.

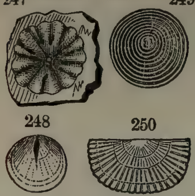

Fig. 247, Bryozoan (?). 248–250, BRACHIOPODS: 248, Lingulella Matthewi; 249, Discina Acadica; 250, Orthis Billingsii.

Among Articulates, the Worms are fleshy species; and only their borings or tracks remain in the rocks. The borings or burrows are vertical in the beds, and generally in pairs, in accordance with the habit of the boring sea-worm, of sandy or muddy sea-shores. The genus to which the common kind is referred is called *Scolithus* (from the Greek for *worm stone*). Some of these burrows, of a kind common in the Potsdam sandstone, are represented in Fig. 265. The species of the St. John beds have not been particularly described.

Trilobites[1] are very numerous in rocks of the Acadian epoch, as

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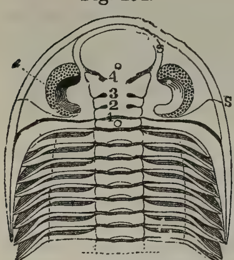
heimia, Terebratella, Megerlia, Kraussia,* Bouchardia,* Morrisia, Argiope; in the *Thecidium family*, Thecidium; in the *Rhynchonella family*, Rhynchonella; in the *Crania family*, Crania; in the *Discina family*, Discina; in the *Lingula family*, Lingula. There are no living species of the *Orthis*, *Productus*, and *Spirifer* families. *Calceola* (Fig. 242) is not now regarded as a Brachiopod.

[1] The genera are distinguished mainly by the form and markings of the head and tail portions, and the form and position of the eyes. The large anterior segment is the head or buckler; the posterior, when shield-shaped and combining two or more segments, the *pygidium*. The middle area of the head, which is often very convex, is the *glabella;* the parts of the head either side of the glabella, the *cheeks;* a suture running from the anterior side of the eye forward or outward, and from the posterior side of the eye outward (*s s* in the figure), the *facial suture;* a prominent piece on the under surface of the head, covering the mouth, the *hypostome.* The eyes may be very large, as in *Dalmanites* (Fig. 254), *Phacops*, and *Asaphus* (Fig. 360), or small, as in *Homalonotus;* or not at all projecting, as in *Trinucleus* (Fig. 363); and may also differ in position in different genera.

Fig. 254.



Dalmanites Hausmanni.

The glabella may be broader *anteriorly*, as in *Phacops*, *Dalmanites*, *Trinucleus;* or broader *posteriorly*, as in *Calymene* (Fig. 361), *Bathyurus* (Fig. 301); and it may vary otherwise in form; or it may be ill defined, as in *Asaphus* (Fig. 360) and *Illænus* (Fig. 393). It may have no furrows across its surface, or one or more up to four (or rarely five). The four may be numbered, beginning behind, No. 1, 2, 3, 4 (Fig. 254). These furrows may extend entirely across, or be divided at middle as Nos. 2, 3, 4. *Asaphus* (Fig. 360) and *Illænus* (Fig. 393) have none of these furrows; *Trinucleus* (Fig. 363) has No. 1 faint or obsolete; *Triarthrus* (Fig. 360), *Homalonotus*, *Bathyurus* have No. 1 entire; *Dicellocephalus* (Fig. 268) has Nos. 1 and 2 entire, and 3 divided; *Calymene* (Figs. 167, 361), *Dalmanites*, *Crypheus*, *Ogygia*, *Ceraurus*, *Proëtus*, have No. 1 entire, and 2, 3, 4 divided, but 4 is sometimes obsolete. *Sao* (Fig. 281) has No. 1 entire, and 2, 3, 4 divided; but there is a median longitudinal depression in which 2, 3, 4 from either side coalesce. In one group, the genus *Lichas*, the glabella has, on either side, one or two longitudinal or

well as in the following. Fig. 251 represents one of the largest kinds, a species of *Paradoxides*, that at times exceeded twenty inches in length. It is from the beds near Braintree, Mass. Fig. 252 represents the cephalic shield of another Trilobite, of the genus *Conocoryphe*, from St. John; and Fig. 253, the cephalic and caudal (head and tail) portions of another genus, *Agnostus*. These three genera of Trilobites have many species in Primordial rocks, and mark this era in the history of life.

Figs. 251-253.

Trilobites. Fig. 251, Paradoxides Harlani (×⅓); 252, Conocoryphe Matthewi; 253, Agnostus Acadica — *a*, head, *b*, caudal part.

In the rocks of the Potsdam epoch, various fossil sponges are found (Fig. 261, p. 177); remains of *Crinoids;* Brachiopods of the genera *Lingulella* (Figs. 262, 263, 264), *Orthis*, etc.; and various *Trilobites* (Figs. 266–269), but among them none that were alive in the Acadian epoch, and none of the genus *Paradoxides*. Nearly 100 species of Trilobites have been described from the American Primordial rocks.

There are also the first of *Graptolites*, delicate plume-like fossils, so named from the Greek γράφω, *I write*. They are described as Hydroid Acalephs on page 130. Fig. 270 represents one species, natural size, and Fig. 271, a portion of a branch enlarged: it is from the Wisconsin beds.

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oblique lobes (Figs. 362, 449). The furrows, as shown in the genus *Paradoxides*, correspond to articulations of the body. They are mostly obliterated in the higher Trilobites where the head-shield is most compact, and are most distinct in the lowest, like *Paradoxides*, being a part of that general looseness of body that marks inferior grade.

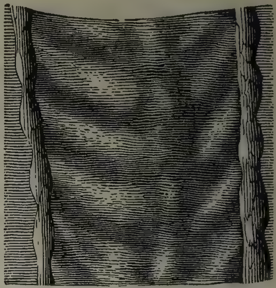
The position of the facial suture (see p. 174 and *s s* in Fig. 254) affords characters for distinguishing genera; also the number of segments of the body (in *Agnostus*, Fig. 279, the number is very small, and the head and pygidium are almost in contact); the continuation of the free movable segments to the posterior extremity, or the union of the posterior into a shield (called the pygidium); in some cases the breadth of the middle lobe of the body as compared with the lateral, it being very broad in *Homalonotus* (Fig. 450); the form of the fold of the shell beneath the head at its anterior margin; the shape of the hypostome; the capability of folding into a ball by bringing the abdomen to the head, as in *Calymene*, *Isotelus*, *Phacops*.

Besides the remains of Crustaceans, there are, at Beauharnois, in Canada, and elsewhere, tracks called *Protichnites* (Fig. 258), which

Fig. 258.

Protichnites 7-notatus (× 1/6)

Fig. 259.



Track of a Trilobite (× 1/6).

are supposed to have been made by large Crustaceans having stout legs like the modern Limulus: they need further explanation. A very different kind of track, also first made known by Logan (Fig. 259), occurs in the same Canada rocks. It is six and three-quarter inches wide; and one trail is continuous for thirteen feet. It was probably made by the clusters of foliaceous swimming or crawling organs of one of the great Trilobites.

Characteristic Species.

1. Acadian Epoch.

1. *Plants.*

Algæ. — Several Fucoids; also *Eophyton Linnæanum* (a fossil of doubtful character, first described in Sweden), from near Quebec, and in the auriferous rocks of Nova Scotia.

2. *Animals.*

1. **Radiates.** — None yet described.

2. **Mollusks.** — *a. Bryozoans.* — None are known.

b. Brachiopods. — Fig. 248, *Lingulella Matthewi* Hartt., St. John, N. B.; *L.* ——— ? ib.; *Obolella transversa* Htt., ib.; 249, *Discina Acadica* Htt., ib.; 250, *Orthis Billingsii* Htt., ib.

c. Of undetermined relations. — *Aspidella Terranovica* B., from supposed Huronian in S. E. Newfoundland.

3. **Articulates.** — *a. Worms. Scolithus* ———*?; Arenicolites spiralis?* Lovell, from S. E. Newfoundland, with *Eophyton.*

b. Crustaceans: all thus far known are Trilobites. — Fig 252, *Conocoryphe* (*Conocephalites*) *Matthewi* Htt., besides 14 other species of the genus, from St. John, N. B.; 253, *Agnostus Acadicus* Htt., and also another species, ib.; *Paradoxides lamellatus* Htt., with four other species, from St. John; *P. Bennettii* Salter, St. Mary's Bay, Newfoundland; 251, *Paradoxides Harlani* Green, Braintree, Mass.; *Bathyurus gregarius* B., St. Mary's Bay, Newf.

2. Potsdam Epoch.

Some of the Vermont fossils of this epoch are identical with those from Anse au Loup, on the north shore of the Straits of Belle Isle, Newfoundland.

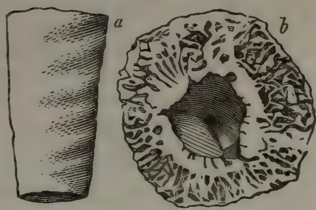
1. *Plants.*

Two species of the genus of Fucoids, *Palæophycus*, from Straits of Belle Isle, have been described by Billings, as *P. incipiens* and *P. congregatus;* and the first of these occurs also near Swanton, Vt.

2. *Animals.*

Protozoans. — *Sponges.* — Fig. 261, *Archæocyathus Atlanticus* B., from the Straits of Belle Isle: *a*, external form, diminished one-half; *b*, a polished transverse section, natural size, showing an irregularity of structure, like that of a sponge; *Archæocyathellus Rensselaericus* Ford, at Troy.

Fig. 261.



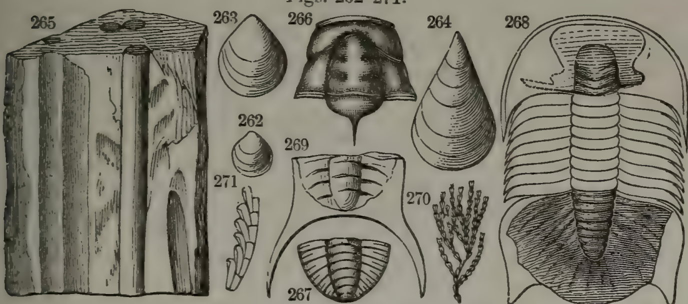
Archæocyathus Atlanticus.

The Green Sand of the Wisconsin and Tennessee beds suggests the probable existence of *Rhizopods*, since the shells of these Protozoans have been found to be connected with the origin of this material in the Silurian rocks of Europe, as well as in those of the Cretaceous in Europe and America.

Radiates. — *a. Polyps.* — None are known.

b. Acalephs. — Figs. 270, 271, *Dendrograptus Hallianus*, from St. Croix, Minnesota.

Figs. 262–271.



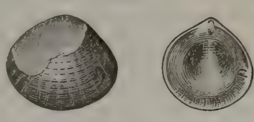
Figs. 262, 263, Lingulella prima; 264, L antiqua; 265, Scolithus linearis; 266, 267, Conocoryphe minuta, head and tail shields (×4); 268, Dicellocephalus Minnesotensis (×¼); 269, C. Iowensis; 270, 271, Dendrograptus Hallianus.

c. Echinoderms. — Stems of Crinoids, at La Grange, Minnesota (probably Cystidean); and a single disk at Keeseville, N. Y.

Mollusks. — *a. Bryozoans.* — None are known.

b. Brachiopods. — Fig. 262, *Lingulella* (formerly *Lingula*) *prima* Conrad, from Keeseville, N. Y.; 263, same, from Lake Superior (Tequamenon Bay), and from St. Croix, Wis.; 264, *L. antiqua* H. (or *L. acuminata* Conrad), from St. Croix, — a much larger specimen than those of New York, but varying much in size and form. It is common also in Canada. Other *Lingulæ* occur in Wisconsin and Canada. *Obolella ? polita* Hall (Obolus Apollinis *Owen*) from near the mouth of Black River in Iowa. Species of *Obolella* have been described from Troy, N. Y., and Wisconsin, and one (*O. nana*, Figs. 272, 273), from the Black Hills of Dakota; *Obolus Labradoricus* B., Straits Belle Isle; *Obolella chromatica* B., ib.; *Obolella* (*Kutorgina*) *cingulata* B. (recently shown to be *O. Phillipsii* Salter, of middle Lingula flags of Great Britain); *O. desquamata* Hall, and other species, Troy; *Camerella antiquata* B., Swanton; *Orthisina*

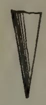
Figs. 272, 273.



Obolella nana.

festinata B., $1\frac{1}{2}$ m. E. of Swanton, Vt.; also, at same locality, another *Orthisina* and an *Orthis*, and at the Straits of Belle Isle, two different species of *Orthis* and another *Orthisina;* on the St. Croix, *Orthis Pepina* Hall.

Fig. 274.



Hyolites gregarius.

c. Lamellibranchs. — An undetermined one is reported from Troy.

d. Pteropods. — Fig. 274, *Hyolites* (*Theca*) *gregarius* M. & H., from the Big Horn Mountains, lat. 43° N., long. 107° W., where they are crowded together in great numbers on the slabs. *H. impar* Ford and *H. Americanus* Ford occur near Troy. A species has also been found at Keeseville, N. Y.

e. Gasteropods. — Imperfect specimens of a *Pleurotomaria* and *Ophileta compacta*, in Canada, and the former also at Keeseville, N. Y.; a Gasteropod of the form of a *Capulus*, in Texas (B. F. Shumard); *Platyceras primordiale* H., at Trempaleau, Wis.; *Euomphalus? vaticinus* H., Lagrange Mt., Minn.

f. Cephalopods. — Two species of *Orthoceras* occur in the Potsdam of Canada, in the top layers, with the *Lingula antiqua* (or *acuminata*).

Articulates. — *a. Worms.* — Fig. 265, casts of worm-holes of *Scolithus linearis* H., common in New York, Canada, Pennsylvania, Tennessee, and occurring also at the Straits of Belle Isle. The *Fucoides? duplex* H. (Foster & Whitney's Lake Superior Report, pl. 23) probably belongs to another species of worm. *Serpulites Murchisoni* H. occurs in Wisconsin. *Salterella rugosa* B., and *S. pulchella* B., slender conical shells, one half inch, or so, long, from Straits of Belle Isle, are regarded by Billings as allied to *Serpulites* among Worms, but by others as shells of Pteropods. The *S. pulchella* occurs in the Winooski Limestone in Vermont.

b. Crustaceans. — (1.) *Phyllopods.* — No Phyllopods have been found, although they occur in the British Primordial. (2.) *Ostracoids.* — *Leperditia Trojensis* Ford, at Troy. (3.) *Trilobites.* — Figs. 266, 267, *Conocoryphe minuta* Bradley, from Keeseville, N. Y., and also from Wisconsin, 266, the head-shield or buckler, with the side-pieces wanting, none having been found united to the head; 267, the pygidium; *C. Adamsii* B., and *C. Vulcanus* B., at Highgate, Vt., and the former in Newfoundland; *C.* (*Atops*) *trilineata* Emmons, at Troy and Bald Mountain, N. Y.; *C. Teucer* B., in Swanton, Vt.; *C. Iowensis* Shum. (Fig. 269), from near the mouth of Black River, Iowa. Fig. 268, *Dicellocephalus Minnesotensis* D. D. Owen, a trilobite six inches long, from the upper beds, Lake St. Croix, Minnesota. The name of this genus is from δίκελλη, *a shovel*, and κεφαλή, *head* (whence the spelling above). The same region in Wisconsin affords species of *Agnostus*, *Agraulos*, *Ptychaspis*, *Chariocephalus*, *Aglaspis*, and *Illænurus*, the last two only in the upper beds. Species of *Agnostus*, *Agraulos*, *Dicellocephalus*, and *Conocoryphe*, in Texas. *Agraulos? Oweni* M. & H. is from the Black Hills, Dakota, and the Big Horn Mountains; also, *Olenellus* (*Elliptocephalus*) *asaphoides* Emmons, Bald Mountain and Troy, N. Y., a very large species; *Olenellus Thompsoni* Hall, Swanton, also Straits of Belle Isle and East arm of Bonne Bay, Newfoundland, and Bradore and Forteau Bays, Labrador; *O. Vermontana*, Swanton and Straits of Belle Isle, and also Bradore and Forteau Bays, Labrador; *Peltura holopyga* Hall, Vermont shales; *Agnostus nobilis* Ford, Troy, N. Y.; *Bathyurus senectus* B., *B. parvulus* B., Straits of Belle Isle; *B. vetustus* and *B. perplexus* B., from East arm of Bonne Bay, Newfoundland.

Fig. 259 represents a track, probably of a large trilobite, from near Perth, Canada, described by Logan, who names it *Climactichnites Wilsoni.* Fig. 258, track, supposed to be Crustacean, called *Protichnites 7-notatus* Owen.

The following are the genera of Trilobites represented in American Primordial rocks: 1. *Those peculiar to the Primordial:* Paradoxides, Olenellus, Aglaspis, Chariocephalus, Illænurus, Pemphigaspis, Triarthrella. 2. *Those occurring also in the following or Canadian period:* Agnostus, Amphion, Agraulos, Bathyurus, Conocoryphe, Dicellocephalus, Menocephalus, Crepicephalus, Ptychaspis, Bathynotus (Billings). The genus most abundant in species is *Conocoryphe.* Of all, only *Bathyurus* continues into the Trenton period. *Triarthrella* is very near *Triarthrus* of the Trenton.

2. European.

The Primordial or Cambrian rocks of Great Britain outcrop in North and South Wales, and in Shropshire (or Salop), just east of Wales. The lowest rocks of the series are the shales and sandstones of the Longmynd, in Shropshire, and of northern Wales, the maximum thickness of which has been estimated at 28,000 feet. The Penrhyn and Llanberis slates are in the upper part of the series in north Wales, near the Menai Straits. In southwest Wales, there are (1) the Harlech grits, overlaid by (2) the Menevian group. Similar rocks occur in County Wicklow and County Dublin, in Ireland, which are supposed to be of the same age. The Longmynd rocks are the *Lower Cambrian* of Sedgwick. In northwest Scotland, beds referred to the Cambrian, consisting of red and purple sandstones and conglomerates, overlie unconformably the Archæan.

The Cambrian rocks of the Longmynd and north Wales are overlaid *conformably* by the *Lingula flags*, a series of beds of shale, grit, and sandstone, 3,000 to 4,000 feet thick. The three British divisions of the Primordial are, 1, *Lower Cambrian;* 2, *Menevian*, or *Upper Cambrian*, corresponding to the American Acadian group, and containing species of *Paradoxides;* 3, the *Lingula flags*, or upper part of them, affording, like the American rocks of the Potsdam period, no *Paradoxides.*

In Lapland, Norway, and Sweden, there is a Primordial sandstone overlaid by schists, the lowest beds passing at times into a conglomerate; the regions A, B of the geologist Angelin. In Bohemia, the lowest Primordial beds are schists 1,200 feet thick, called by Barrande *Protozoic schists*, or the Primordial Zone, and numbered C in his series, —his A, B consisting of schists and conglomerates conformable to C. Until recently, B was thought to contain no trace of life, and therefore to be below the Primordial; but worm-burrows have been reported to occur in some of these inferior beds. South of Hof, in Bavaria, there are other rocks of the Primordial zone.

1. Life. — 1. *Cambrian.* — The Longmynd rocks have afforded worm-burrows, the species named *Arenicolites didyma.* From the Harlech beds of the Upper Cambrian,

Figs. 276–282.

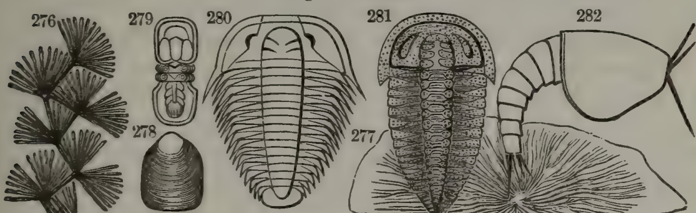


Fig. 276, Oldhamia antiqua; 277, O. radiata; 278, Lingulella Davisii; 279, Agnostus Rex; 280, Olenus micrurus; 281, Sao hirsuta (×½); 282, Hymenocaris vermicauda (×½).

many species have been described, including *Pteropods*, *Brachiopods*, *Phyllopods*, *Trilobites* and *Annelid* tracks. And from the Menevian, a larger number, among

them species of *Paradoxides* (one, two feet long), *Conocoryphe, Agnostus, Leperditia,* and *Theca;* also, the *Oldhamia antiqua*, Fig. 276, a species, probably vegetable, found with *O. radiata*, Fig. 277, at Bray Head, in Wicklow, Ireland.

From the Harlech grits have been obtained species of *Paradoxides, Conocephalites* (Conocoryphe), *Microdiscus*, and *Plutonia Sedgwickii*, among Trilobites; a species of *Theca* among Pteropods; and a number of kinds of worm-burrows; also the *Palæopyge Ramsayi* S., a supposed trilobite.

In the Menevian beds have been found: Among PROTOZOANS, *Protospongia fenestrata* S.; among MOLLUSKS, *Theca corrugata* S.; among TRILOBITES, *Paradoxides Davidis* S., *P. Aurora* S., *Apopolenus* (near Paradoxides) *Henrici* S., *A. Salteri* Hicks, *Conocoryphe* (Conocephalites) *variolaris* S., *C. bufo*, Hicks, *C.* (?) *humerosa* S., *C. applanata* S., *Agnostus princeps* S., *Erynnis venulosa* S., *Microdiscus punctatus* S.; among OSTRACOIDS, *Leperditia Solvensis* Jones, with other species of this group; among WORMS, at Bray Head, *Histioderma Hibernicum* Kinahan.

The Lingula flags, as restricted, contain the Brachiopod *Lingulella Davisii* McCoy, Fig. 278, *Olenus micrurus* S., Fig. 280, species of *Conocoryphe, Dicellocephalus*, etc., *Hymenocaris vermicauda*, Salter, Fig. 282, etc.

Some of the Bohemian Primordial species are: *Agnostus Rex* Barr., Fig. 279; *A. integer* Barr., from Skrey, *Paradoxides Bohemicus* Barr., *Sao hirsuta* Barr., Fig. 281; *Elliptocephalus depressus* S., *Conocoryphe invita* S., *C. striata* Barr., some species of *Cystids*. Bavarian serpentine, of Primordial age, has afforded Gümbel the *Eozoon Bavaricum*. Sweden has afforded the British species, *Paradoxides Hicksii* S., besides other fossils.

No Polyp corals have been found in any Primordial beds. Over seventy species of Primordial Trilobites have been discovered in Scandinavia, and nearly thirty in Bohemia. The *Eophyton Sandstone* at Lugnas, in Sweden, which has been referred to the Cambrian, and is of the "Fucoid region" of the Swedish geologists, has afforded a *Lingula*, besides species of a genus of plants called *Eophyton*, which have been considered terrestrial plants, and are placed by Linnarson near the genus *Rhachiopteris* of Unger. The absence of the successors to these species in the later Lower Silurian throws doubt on this reference of them.

IV. General Observations.

1. **North American Geography.** — On p. 149 a map is given, purporting to represent the general outline of North America at the close of the Archæan or during the earlier part of the Silurian. It is there stated that there may have been other lands above the water, large and small, in the great continental sea; but that the continent, in a general way already defined as to its ultimate outline, lay at no great depth beneath the surface. The facts gathered from the rocks of the Primordial era throw additional light on early American geography.

The fact that the depositions of the Acadian period occur only on the *border* of the continent — along eastern Newfoundland, New Brunswick, and Massachusetts — and nowhere over the interior, should it be sustained by future observations, would show that, as the Silurian age opened, the continent, on the east at least, was raised nearly to its present limits above the sea. The beds of St. John, New Brunswick, bear evident marks, as Matthew observes, of sea-shore origin. The eastern sea-coast of Acadian time was therefore not far from the present line; and the dry land of North America for a while may have approximated in extent to that now existing.

In the next or Potsdam epoch, there were beach deposits of sand in progress about the shores of the Archæan dry land, but in Vermont mostly shales, with some limestones, indicating deeper waters off the Archæan coasts. West of Vermont, this coast line bent around the Adirondack region of northern New York and Canada, as marked out by the distribution of the Potsdam. The Potsdam rocks of New York and Canada indicate their beach or shallow-water origin, by their foot-prints, worm-borings, ripple-marks and mud-cracks (p. 169). Similar evidences of shallow water are observed also in the Potsdam rocks of Pennsylvania and Tennessee. Thus we are enabled to run a line of soundings along the continental sea of the Potsdam era. The materials of the sandstones were the moving sands and pebbles of the shores and shallow seas; and the animals which had living places over these flats and sea bottoms found in them also a burial place, to remain as fossils and become testimony as to the early life of the world. The accompanying sketch, by J. D. Whitney, represents the Archæan at Carp River, Michigan, overlaid unconformably by beds of Potsdam

Fig. 283.

Unconformability at Carp River, Michigan.

sandstone — a portion of the "Pictured rocks" of the southern shores of Lake Superior. They are here shown to be the sand-beds that were made in the seas of the era, against a seashore ledge of crystalline Archæan rocks; and that finally became consolidated, and also somewhat tilted.

2. **Climate.** — No marked difference between the life of the Primordial period in warm and cold latitudes has been observed; and

there is wanting, therefore, all evidence of a diversity of climate and of oceanic temperature over the earth's surface. With a warm and equable climate, the atmosphere would have been moist and the skies much clouded; but storms would have been less frequent or violent than now. The eyes of the Trilobite, as Buckland observes, indicate that there was the full light of day, and therefore that sunshine alternated with the clouds as now.

So far as has been deciphered in the history of the Primordial period, there was no green herbage over the exposed hills; and no sounds were in the air save those of lifeless nature, — the moving waters, the tempest and the earthquake.

3. **Exterminations of life.** — The life of the Primordial period changed much during its course; and, at one time — the close of the Acadian epoch — there was a general extermination of the species about the eastern portion of the continent; for no species of this epoch have yet been found in the higher rocks. Among the Trilobites, the genus *Paradoxides*, some of whose species were the largest of known Crustaceans, became extinct; most of the other genera remained, but were represented by new species. No Trilobites of the Primordial extend up, so far as known, into the beds of the next period.

V. Disturbances during the progress of the Primordial period.

In Newfoundland, the beds of the Potsdam division lie unconformably over those of the Acadian, indicating an epoch of disturbance between. No direct evidence of a similar disturbance over the rest of North America has yet been made known, beyond the fact of the destruction of the *Acadian* life above mentioned, and the additional observation, by F. H. Bradley, that at Henry's Lake, Idaho, a quartzyte (probably Potsdam) underlies unconformably the beds of the Quebec group. The fact, stated by Emmons, that pebbles of the Potsdam sandstone are included in a conglomerate at the base of the Calciferous, seems to show that the consolidation of the Potsdam had taken place before the Calciferous era.

2. CANADIAN PERIOD.

1. American.

Epochs. — 1. The Calciferous, or that of the Calciferous sandstone of New York, etc. 2. The Quebec, or that of the Quebec group in Canada. 3. The Chazy, or that of the Chazy limestone.

I. Rocks: their kinds and distribution.

The area over which the rocks of the Canadian period are the surface rocks follows nearly the border of the Archæan in Northern New

York, Canada, Northern Michigan, and Wisconsin, making, along with the Primordial area, the northern portion of the area marked as Lower Silurian on the map (p. 165). They also come out to view along the Green Mountains, the eastern part of the Appalachians from New Jersey southwestward, and in Missouri and Arkansas; and farther west, in the Rocky Mountain region.

The beds of the Calciferous epoch consist of calcareous sandstone with some magnesian limestone in Canada and Northern New York, and are mainly magnesian limestones in the Mississippi basin. The Quebec group consists of shales, sandstone, and thin beds of limestone near Quebec; but are of limestone chiefly in East Tennessee, and in the Rocky Mountain region. It may be an upper stratum of the Calciferous formation.

The Chazy — so named from a locality in Northern New York — is an extensive limestone formation, occurring near the Archæan in Northern New York and Canada, stretching westward north of Lake Huron, and making part of the "Magnesian limestones" of Missouri. It is represented by a sandstone — the "St. Peter's sandstone" — in Wisconsin and Iowa.

The crystalline limestone or "marble" of the Green Mountains has been proved by fossils to include the Calciferous and Chazy, and also the Trenton limestone; and that of Eastern Pennsylvania is probably of equivalent age, Chazy and other fossils having been found by Prime in Lehigh County. The St. Peter's sandstone, overlying the Lower Magnesian limestone of Wisconsin and Iowa, is referred to the Chazy epoch.

1. Calciferous epoch. — *a. Interior Continental basin.* — In New York and Canada, the Calciferous formation often consists below of impure magnesian limestone of a dark gray color. In many places in northern New York, the layers are very hard and siliceous, and contain geodes of quartz crystals, as at Diamond Rock, Lake George, and at Middleville and elsewhere in Herkimer County, etc. The mixture of calcareous with hard siliceous characteristics is a striking peculiarity of the rock. Owing to the lime present, much of it becomes rough from weathering. Besides quartz and calcite, barite, celestite, gypsum and occasionally blende and anthracite, are found in its cavities. The limestone often contains chert or hornstone.

The "Lower Magnesian Limestone" of Missouri, mostly unfossiliferous, is referred by Swallow to the Calciferous epoch. He makes it to consist of four limestone strata, 190 to 350 feet thick, which he numbers, beginning above, 1 to 4, and, between these, thinner strata of sandstone, 50 to 125 feet thick. Shumard has described fossils from the third which are regarded as Calciferous. In the other strata, above, the rest of the Canadian period may be represented. In Wisconsin, according to Hall, the Lower Magnesian limestone is in all only 200 to 250 feet thick; and at top there is the St. Peter's sandstone, mostly 60 to 100 feet thick, referred to the Chazy. Farther north, near Lake Pepin, there are, beneath the Magnesian limestones, several hundred feet of sandstone, probably Calciferous in age. Along the south shore of Lake Superior, on Keweenaw Point and elsewhere, there is sandstone only. On Keweenaw Point, it underlies at one or two places a thin, fossiliferous limestone of the Black River and Trenton

age, showing that it is older. The rocks on Keweenaw Point include 8.000 to 16,000 feet of sandstone and conglomerate (Whitney), along with intersecting trap rocks and some intercalated scoria-conglomerate. East of this point, there are in the same sandstone formation the Pictured Rocks of the coast — fine sandstones blotched or mottled with red or light gray. Westward, the sandstone extends to the west end of the lake, and then northward and eastward to Thunder Bay and Neepigon Bay. The rocks of Isle Royale and Michipicoten Island are of the same age. The formation is remarkable for its copper mines. In Canada, the Calciferous sandrock has a thickness of 50 to 300 feet.

b. Appalachian Region. — The *Auroral* series of Rogers, in Pennsylvania, corresponds, according to him, to the Calciferous, Chazy, and Black River beds, and consists mainly of magnesian limestone; it is from 2,500 to 5,000 or 6,000 feet in thickness.

In eastern Tennessee, near Knoxville, the Calciferous includes the "Knox sandstone" of Safford, the lower member of the Knox Group (F. H. Bradley).

2. Quebec epoch. — Near Quebec, the beds are largely developed on the island of Orleans and in the district around Point Levis. From the *Levis* beds, Logan separates the upper part, occurring more to the southward and southeastward, which is destitute of fossils and consists mainly of copper-bearing metamorphic schists, and designates it the *Lauzon* division. He also adds to the series the "Sillery Sandstone" (so called from a place near Quebec) as an upper member, the actual connection of which with the system is not clear.

In the vicinity of Quebec, the thickness of the Levis beds is said to be 5,000 feet; 4,000 feet of the whole are gray and green shales, 155 feet intercalated beds of limestone (half of it limestone-conglomerate), and 700 feet gray sandstones partly shaly. The shales are either calcareo-magnesian, argillaceous or arenaceous. Many of the beds abound in fossils. Logan supposed the Quebec slates to extend south along the Hudson River; but the discovery of fossils of the Trenton period in Dutchess County, at Poughkeepsie, aud elsewhere, has proved this to be an error.

In northwestern Newfoundland, the thickness of the "Quebec series" is 6,600 feet, — the lower 3,200 feet mostly limestones, and the rest sandstones and shales, with some conglomerate limestone. The upper 2,000 feet are separated by Logan and Billings as "Sillery;" the next 1,400, of sandstones and shales and some limestones, as "Levis," and the lower beds, 1,839 feet thick, of limestones, as Calciferous. Between these Calciferous beds and those referred on paleontological evidence to the Levis, there are 2,061 feet of fossiliferous limestone, which have no equivalents in Canada, and are called *Upper Calciferous,* in distinction from the New York beds which are hence made *Lower Calciferous.* "It thus appears that the 'Levis' formation not only lies above the Calciferous, but more than 2,000 feet above it." (Billings.)

The Quebec group in Tennessee, about Knoxville, includes the shale and dolomite of the "Knox group" of Safford (F. H. Bradley): the base of the dolomite abounds in trilobites characteristic of the group. In Idaho, Bradley found the group on the east side of Malade valley, six miles south of Malade city, 2,000 feet thick, mostly of limestone, underlaid and overlaid by quartzyte; and in the Teton range, at the base of the limestones over the granites of the range (Am. Jour. Sci., III. iv., vi.), and separated from the latter by only a few feet of quartzyte referred to the Potsdam epoch.

3. Chazy epoch. — (*a.*) *Interior Continental basin.* — The Chazy limestone outcrops at different places in northern New York, in the vicinity of the Archæan (though not along its more southern border); also in Canada, around the Trenton limestone of the Ottawa basin. The thickness in some parts of New York is 100 to 150 feet. Occasionally, it graduates into the next rock below, the Calciferous sandrock, so that the two are separated with difficulty.

The reference of part of the limestone formation of the Green Mountain region to the Calciferous and Chazy epochs, extending through Vermont, Western Massachusetts and Connecticut, and the eastern border of New York, is based on the discovery of fossils in it in Vermont by A. Wing, among them a Crinoidal plate of *Palæocystites tenuira-*

diatus, a characteristic Chazy species, and *Pleurotomaria staminea*, Dn. (as identified by Billings) at West Rutland, and also the *Maclurea magna*, and a *Calciferous Orthoceras*, two miles north of Middlebury, together with other fossils at other localities (see Am. Jour. Sci., III. xiii., xiv., 1877).

The rocks supposed to be equivalents of the Chazy in the Mississippi basin are mentioned on the preceding page. A limestone of the age has been stated to occur in the Winnipeg region, west of the Archæan.

(*c.*) *Appalachian region.* — The Chazy has not been distinguished from the Trenton in the Green Mountains, or in Pennsylvania; in the latter State, there is a magnesian limestone, according to H. D. Rogers. Chazy fossils have been found by Prime in the limestone of Lehigh County.

In East Tennessee, the Chazy is represented by from 50 to 600 feet of blue and drab, more or less concretionary, argillaceous limestone ("Maclurea limestone" of Safford).

(*d.*) *Arctic region.* — Limestone strata, containing Chazy fossils, have been observed in the *Arctic*, on King William's Island, North Devon, and at Depot Bay in Bellot's Strait (lat. 72°, long. 94°). The species *Orthoceras moniliforme* Hall and a Maclurea (*M. Arctica* Haughton, near *M. magna*), have been observed. The limestone is in part a cream-colored dolomyte.

Igneous or Intrusive Rocks.

Through New York and the States directly West, no evidences of disturbance have been observed that can be traced to this period. The rocks are for the most part nearly horizontal, and in general little altered; and the tilting which is observed appears to have taken place at a later period. But, on Keweenaw Point, the famous copper-region of Lake Superior, the sandstones of this period are associated with trap, — an igneous rock, that was ejected through fissures opened in the earth's crust; and these trap ejections have added much to the accumulations. Some of the conglomerate (according to Foster and Whitney, and Owen) seems to be made of volcanic scoria, like the tufa of modern volcanoes, as if the ejections had been submarine, and the cool waters had shattered the hot rock to fragments, and so made the material of the conglomerate; and, as many of the masses are not rounded, these authors infer that it was piled up rapidly during the igneous action. Dr. D. D. Owen represents the trap as often in layers, alternating with shale and other rocks, indicating eruptions at different times. The trap rocks of Lake Superior present many scenes of basaltic columns of remarkable grandeur. Some of them are represented and described in the Geological Report on Wisconsin, Iowa, and Minnesota, by Dr. Owen. The native copper of the Lake Superior region is intimately connected in origin with the history of the trap and sandstone.

II. Economical Products.

Copper mines are numerous in the rocks referred to this period, and many of them are highly productive. Those of Keweenaw Point, on the southern border of Lake Superior, are among the most remark-

able in the world. The copper is mostly in the native state, or pure copper, and occurs in great masses or sheets, as well as in strings and grains. The strings are really made up of imperfect crystals. One great sheet of copper, opened to view in the course of the mining, was forty feet long, and weighed, by estimate, two hundred tons. Much of the copper contains native silver, in imbedded grains, often large enough to be visible, and sometimes an inch or more across; some specimens are spotted white with the more precious metal.

In addition to copper, the rocks contain the usual trap minerals, — zeolites, datolite, calcite, quartz; and some calcite, datolite, and analcite crystals are implanted on or about threads of copper, showing that they are of subsequent origin. The copper occurs in irregular veins in both the trap and the sandstone, and also in cavities; and, whenever the trap was thrown out as a melted rock, the copper probably came up, having apparently been derived from copper-ores in some inferior Archæan rocks, through which the liquid trap passed on its way upward. The extent to which the rock and its cavities are penetrated and filled with copper shows that the metal must have been introduced by some process before the rock had cooled.

There are also rich silver mines. "Silver Islet," adjoining the north shore of Lake Superior, is already a noted mining region; the ore deposits have been found to be continued over the country to the north.

In Eastern Canada, copper ores have been observed in upward of 500 localities in rocks of the Quebec group. The ores are the yellow sulphid or chalcopyrite, chalcocite (vitreous copper) and bornite. There are also many localities along the north shore of Lake Superior.

The Quebec group also affords, in Canada, magnetic and specular iron; chromic iron, in serpentine, of workable value, one bed, in Ham, three to four feet thick; native antimony and other ores of this metal, in Ham.

The lead mines in Washington, Jefferson, and Madison Counties, Missouri, and in Arkansas, occur in the Lower Magnesian limestone. In Jefferson County, Missouri, as also in Tennessee and southwestern Virginia, the ores of zinc, calamine, and smithsonite, as well as blende, occur with the lead ore or galenite.

Quartz crystals occur in great abundance in cavities in the Calciferous sandrock of central New York and East Tennessee, and fissures are often lined with them. A kind of mineral coal, in small lumps, usually concretionary in structure, is found in some of the beds; and fragments are often imbedded in the crystals of quartz, or lie loose in the cavities that afford the crystals.

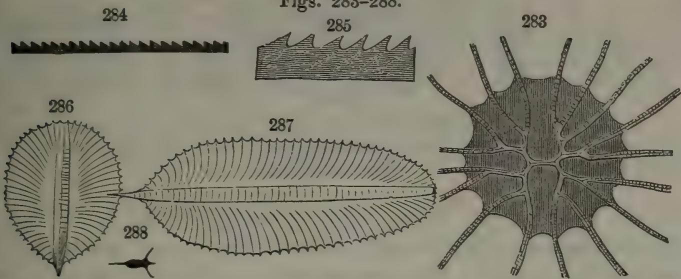
III. Life.

The living species of this period belonged to the same grand divisions as those of the Primordial. The plants thus far discovered were all Algæ or sea-weeds; and the animals were all marine Invertebrates, they belonging to the four sub-kingdoms, Protozoans, Radiates, Mollusks, and Articulates.

The *Protozoans* were represented by Rhizopods and Sponges; the *Radiates*, by Graptolites and Crinoids, but very sparingly by true Polyp corals; the *Mollusks*, by species of all the grand divisions, from the lowest, that of Bryozoans, to the highest, that of Cephalopods; the *Articulates* by Worms and Crustaceans, and, among Crustaceans, by a great number and diversity of Trilobites.

Graptolites, of which some of the forms are represented in the following figures, were exceedingly numerous; over fifty species have

Figs. 283–288.



Figs. 283, 284, 285, Graptolithus Logani; 286, 287, Phyllograptus typus; 288, the young of a Graptolite.

been found in the Quebec group. These feathery species appear to have grown in immense numbers over the muddy sea-bottom, and, probably, as observed by Hall, in the still waters at considerable depths (probably some hundreds of feet), for they are especially abundant in the fine-grained shales and slates of the era. Each branchlet or stem, as explained on p. 130, was margined with little flower-like animals, looking like polyps.

Among the Mollusks, Gasteropods (Univalves) were rather common. Figures 290, 291, 292 are some examples. Lamellibranchs (Bivalves) were of several species. Pteropods were numerous and large, vastly larger than any living species of this group. Cephalopods appeared under the form of the straight *Orthoceras* (Figs. 293, 294, and 295) — a long, tapering shell, *chambered* like that of the *Nautilus*. Fig. 295 is a specimen with the extremity broken. The name is from ὀρθός, *straight*, and κέρας, *horn*, and alludes to the form of the shell. Besides these "straight horns," there were also some curved species, and others that were coiled up like the Nautilus of the present day.

But the most common of all species of Mollusks, by a hundred fold, were the *Brachiopods*, the characteristic species of the Paleozoic world. Some shells of *Lingulellæ* are two inches or more in length, and resemble much in shape the largest species of Lingula of the present day, though still different. Shells of species of *Orthis* are very abundant; one species is represented in Fig. 289.

Among Trilobites, there were no *Paradoxides*, but large numbers of species of *Bathyurus*, *Dicellocephalus*, *Agnostus*, *Olenus*, *Conocoryphe*, etc., genera that began in the Primordial, and some also of the genera *Asaphus*, *Illænus* and others, which became prominent in the succeeding period. Fig. 300 represents the pygidium, and 299,

Figs. 289-298.

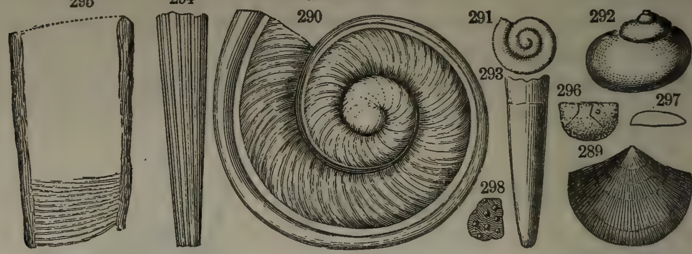
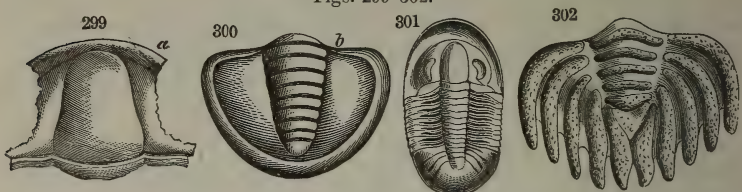


Fig. 289, Orthis (Orthisina?) grandæva; 290, Helicotoma uniangulata; 291, Ophileta levata; 292, Holopea dilucula; 293, 295, Orthoceras primigenium; 294, O. laqueatum; 296, 297, Leperditia Anna; 298, several shells of the same, natural size.

Figs. 299-302.



Figs. 299, 300, Bathyurus Saffordi; 301, Bathyurellus nitidus; 302, Amphion Barrandei.

part of the cephalic shield of a *Bathyurus;* Fig. 301, a species of *Bathyurellus;* 302, the pygidium of an *Amphion*.

The Ostracoids, small Crustaceans that have the body concealed inside of a bivalve shell, in form somewhat like that of a clam, were abundant. Fig. 298 represents several of one of the species; and 296, a side view of the same, enlarged. In the existing seas, the species are from a twentieth to a fourth of an inch in length; while many of those of the Silurian rocks are between a third and half an inch. The shells are so abundant, in the shale of some localities, as completely to cover the surfaces of the thin laminæ.

Characteristic Species.

1. Calciferous Epoch.

Protozoans. — *a. Sponges. Archæocyathus Minganensis* B. occurs at the Mingan Islands, in the lower part of the Calciferous; also *Trichospongia sericea* B.; both of these species appear to contain siliceous spicules.

b. Rhizopods. — The Green sand of some Calciferous beds is good evidence of the existence of Rhizopods (p. 177). *Receptaculites Calciferus* B., Mingan Ids., is supposed by some to be related to the Rhizopods; it looks like a coral pitted closely with small squarish depressions. Dawson suggests that *Archæocyathus* and *Stromatopora* may be Rhizopods and related to *Eozoon.* The *Stromatoporæ* are massive corals, very finely porous; species of this era occurs at Phillipsburg, Canada.

Radiates. — *a. Polyps.* — No Polyp-corals have been found. The genus *Stenopora* is represented among the Canada beds and at the Mingan Islands; but it is probably a genus of Acaleph-corals, — that is, the stony secretion of Hydroid Acalephs (see p. 130).

b. Acalephs. The *Stenopora,* just alluded to. Also *Graptolites,* a tribe very numerously represented in the Quebec group.

Echinoderms. — Crinoidal remains are not common. Among them, Billings has distinguished some stems that probably belong to the genus *Glyptocrinus* (see Fig. 373 for a species of this genus).

Mollusks. — *a. Bryozoans.* — Some authors place the *Stromatopora* here.

b. Brachiopods. — Fig. 289, *Orthis* (*Orthisina ?*) *grandæva* B.; *Lingulella acuminata* Con , *Orthis parva ?* Pander, *Camarella calcifera* B., a species of *Leptæna,* and one of *Strophomena.*

c. Lamellibranchs. — One of the earliest of this group is the *Conocardium Blumenbachii* B., found on the coast of Newfoundland in limestone (p. 184), a shell related to Cardium, and having a siphonal tube. This division, the sinupallial, was far less common in the Silurian than the integripallial or that in which the tube was wanting; and it is therefore the more remarkable that one of the earliest of species should have this high characteristic.

d. Gasteropods. — Many genera of Gasteropods are represented in the Calciferous rocks; and, in all, the aperture of the shell is without a beak. These genera are in part of the Trochus family.

The following are characteristic species: Fig. 290, *Helicotoma* (*Euomphalus* formerly) *uniangulata* H.; 291, *Ophileta levata* V.; *O. complanata* V.; *O. compacta* S., a fine species from Canada, 1½ inches across; 292, *Holopea dilucula* H.; *Pleurotomaria Calcifera* B., from near Beauharnois, Canada; *P. gregaria* B., from St. Ann's, Canada, extremely abundant; *Maclurea matutina* H., from New York and Canada; *Murchisonia Anna* B. (a long turreted shell, approaching the *M. bellicincta,* Fig. 346), from St. Ann's on the island of Montreal, and also the Mingan Islands, in the White limestone and the sandrock below. Species of *Straparollus, Murchisonia* and *Raphistoma* occcur in the third bed of the Magnesian limestone of Missouri (Shumard).

e. Pteropods. — *Ecculiomphalus Canadensis* B. (a shell three inches long, having the form of a curved horn, without transverse partitions within); *E. intortus* B., a smaller species.

f. Cephalopods. — Figs. 293, 295, *Orthoceras primigenium* V., a species having the septa or partitions very closely crowded; 294, *O. laqueatum* H. Other species are *O. Lamarcki* B.; *O. Ozarkense* Shum., from third bed of Magnesian limestone, Ozark County, Missouri; *Lituites Farnsworthi* B., a large species partially coiled, and nearly five inches in its longer diameter; *L. imperator* B., a still larger species, 10½ inches across, having the first three whorls coiled in contact; these Lituites are from the upper part of the Calciferous sandrock of Phillipsburg, Canada East. *Nautilus Pomponius* B., about 3 in. across, from Phillipsburg; *N. ferox* B., Mingan Ids.

Articulates. — *Crustaceans: Trilobites.* — Over 100 American species of Trilobites of the Canadian Period have been described; and 14 of these occur in the Calciferous. Among these 14, there are 2 species of *Amphion* and 6 of *Bathyurus,* both Primordial genera; and 1 of *Asaphus* (*A. canalis*), a genus more fully represented in the Trenton period. Species of *Agraulos* and *Conocoryphe* occur in the *third* magnesian limestone of Missouri (Shumard). The Ostracoid *Leperditia Anna* Jones (Figs. 296, 297, 298) occurs at St. Ann's, Island of Montreal.

2. Quebec Epoch.

Over two hundred and twenty species of fossils have been observed by Mr. Billings in the rocks of the Quebec group; twelve of them are also Calciferous species, and five Chazy.

1. **Protozoans.** — *Sponges. Calathium (?) pannosum* B., *C. Anstedi* B. (?), both from Point Levis and Newfoundland. *Trachium cyathiforme* B., from Newfoundland. The genus *Calathium* commences in the Calciferous. *Stromatopora compacta* B. and *S. rugosa* H.

2. **Radiates.** — *a. Acalephs; Stenopora fibrosa* Goldf. *Graptolites.* Figs. 283–285 represent the *Graptolithus Logani* H., showing, in Fig. 283, the centre of the group, and the furcating mode of branching; in Fig. 284, a portion of a branchlet, and 285, same enlarged. Figs. 286 and 287 are of a leaf-shaped species, the *Phyllograptus typus* H. Fig. 288 represents a form common on the graptolitic shales, which Prof. Hall, to whose investigations we owe our knowledge of the Quebec graptolites, regards as a young graptolite. *b. Echinoderms.* The Star-fish, *Stenaster Huxleyi* B., from Newfoundland. Portions of crinoidal columns.

3. **Mollusks.** — Nearly a hundred species of Mollusks have been described, twenty-eight of which are Brachiopods, forty-two Gasteropods, twenty Cephalopods and only three Lamellibranchs. Among the Brachiopods, besides many species of *Lingula* and *Orthis*, there are others of *Obolella, Discina, Camerella, Leptæna, Strophomena, Rhynchonella, Stricklandinia, Acrotreta.* Among the Lamellibranchs are the *Conocardium* (or *Euchasma*) *Blumenbachii* B., *Eopteria typica* B. (near Pterinea in form), *Ctenodonta Angela* B.

4. **Articulates.** — Over a hundred species of Trilobites have been described, and nearly all by Billings. Of the genera, as he observes, *Agnostus, Amphion, Bathyurus, Conocoryphe, Dicellocephalus, Menocephalus, Crepicephalus, Ptychaspis* and *Bathynotus* (very close to Ptychaspis) occur also in the Primordial. Besides these, there are the genera *Bathyurellus* and *Loganellus* (Primordial in type); also *Ampyx, Ceraurus, Harpides, Harpes, Nileus, Remopleurides, Shumardia, Illænus, Asaphus.* The Levis formation contains four Calciferous species, viz., *Bathyurus Cordai* B., *B. conicus* B., *Amphion Salteri* B., *Asaphus canalis* B.; two Chazy species *Ceraurus* (*Cheirurus*) *prolificus* B. and *Asaphus canalis.*

Figs. 299, 300 represent *Bathyurus Saffordi* B., a common species in Canada, and occurring also in Newfoundland and Idaho — 299, the glabella, 300, the pygidium; 301 *Bathyurellus nitidus* B., from Cow Head, Newfoundland; 302, pygidium of *Amphion Barrandei* B., id.

Only one trilobite (*Asaphus platycephalus* Stokes) of the Quebec group occurs in the Trenton, and this is doubtfully determined (Billings).

A part of the "Quebec group" of Newfoundland, called Upper Calciferous by Logan, contains the Ostracoids, *Leperditia concinnula* B., *L. ventralis* B., *Beyrichia Atlantica* B.

3. Chazy Epoch.

1. **Protozoans.** — *Sponges.* — *Eospongia Rœmeri* and *E. varians* B. occur at the Mingan Islands. Many undescribed species, of several genera, including *Receptaculites*, occur in East Tennessee (Bradley).

2. **Radiates.** — (*a.*) *Polyps.* — Species of *Columnaria* have been described. (*b.*) *Acalephs.* — *Stenopora fibrosa* of Goldfuss.

(*c.*) *Echinoderms.* — The Crinoids include as many known Cystids as Crinids. The following are a few of them: (1.) *Crinids.* — *Palæocrinus striatus* (Fig. 304), the body, showing the radiating ambulacral grooves (five) at top; *Blastoidocrinus carchariædens* B., — the genus apparently of the Pentremite family, a family which makes its next appearance near the top of the Upper Silurian, and abounds in the Subcarboniferous. — (2.) *Cystids.* — *Malocystites Murchisoni* B. (Fig. 305), the body nearly spherical (whence

the name, from the Latin *malum*, an apple), and having no arms, and the ambulacral grooves irregularly radiating; another species is the *Palæocystites tenuiradiatus* B. (Hall's *Actinocrinus tenuiradiatus*), which is common, and has been detected in the granular limestone of West Rutland (Am. Jour. Sci., III. iv. 133.)

3. Mollusks. — (*a.*) *Bryozoans.* — Fig. 306 represents the *Retepora incepta* H., a thin, reticulate coral, the surface of which, magnified, is shown in Fig. 306 *a*; Fig. 307,

Figs. 304–316.

RADIATES. — Fig. 304, Palæocrinus striatus; 305, Malocystis Murchisoni. MOLLUSKS. — 306. Retepora incepta; 307, Ptilodictya fenestrata; 308, Orthis costalis; 309. Leptæna plicifera; 310, Rhynchonella plena; 311, Maclurea magna; 312, M. Logani (×⅓); 313, operculum of same; 314, Scalites angulatus; 315, Bellerophon rotundatus. ARTICULATES. — 316, Leperditia Canadensis, *var.* nana.

Ptilodictya fenestrata H., a small branching species, covered with minute cells, and Fig. 307 *a*, the surface magnified.

(*b.*) *Brachiopods.* — Fig. 308, *Orthis costalis* H.; Fig. 309, *Leptæna plicifera* H.; *L. incrassata* H.; Fig. 310, *Rhynchonella plena* H. (a side-view), a very common species, it almost constituting some beds of the limestone. There are also several Lingulellæ (*L. Lyelli* B., *L. Huronensis* B., etc.); *Orthis imperator* B., a species nearly 1½ in. across, besides several other species of the genus.

(*c.*) *Lamellibranchs.* — *Vanuxemia Montrealensis* B., a species nearly 1½ in. long, related to *Avicula*.

(*d.*) *Gasteropods.* — Fig. 311, *Maclurea magna*, which is very abundant, and sometimes has a diameter of eight inches; Fig. 312, *Maclurea Logani*, showing the shell closed by its operculum; Fig. 313, the operculum, inside-view; Fig. 314, *Scalites angulatus* Con.; Fig. 315, *Bellerophon* (*Bucania*) *rotundatus* H.; *Pleurotomaria Calyx* B., near Montreal.

(*e.*) *Cephalopods* — *Orthoceras recti-annulatum* H; *O. tenuiseptum* H., a large species, with the septa thin and rather crowded; *O. velox* B., Montreal, Mingan Ids.; *O. diffidens* B., Mingan Ids.

4. Articulates. — (*a.*) *Trilobites.* — Among the species there are *Illænus Arcturus*

H.; *I. Bayfieldi* B.? ; *Asaphus obtusus* H.; *Bathyurus Angelini* B.; *Amphion Canadensis* B.

b. Ostracoids. — Fig. 316, *Leperditia Canadensis* Jones, from Grenville, Huntley and elsewhere in Canada; *L. amygdalina* B., from near L'Original, Canada.

The Mollusks common to the Calciferous and Levis, according to Billings, are *Lingula Mantelli, Camerella Calcifera* and *Pleurotomaria Calcifera* (and possibly also *Ophileta uniangulata, Maclurea matutina, M. sordida, Holopea dilucula*). Only the *Camerella varians* is common to the Chazy and Levis. In the lower part of the beds underlying the true Levis beds of Cow Head, Newfoundland, which have been called *Upper Calciferous* by Logan, there are seven trilobites, of which *Amphion Barrandei* and *Asaphus canalis* occur in the Levis. *Orthis Electra* is also common to these beds and the Levis; but the other fossils are either new species, or species that occur in the Chazy and Calciferous. Above these beds, there are 277 feet of rock with still another fauna; and then follow 700 feet of sandstone, and then the true Levis formation, at Cow Head.

European.

Although in North America the rocks of this period have an aggregate thickness of more than 7,000 feet, with 3,000 feet of them limestones, and some of them abound in fossils, their precise equivalents in Europe are not well understood. This is part of the proof that geological changes over the different continents have to a large extent gone forward independently. All that can be positively said is, that the American strata correspond to the *lower part* of the Lower Silurian, above the Primordial, in Europe — and probably to (1) the Tremadoc slates, and (2) the Arenig or Stiper Stones group (Lower Llandeilo) in England; the lower part of Barrande's stage D, in Bohemia, and Angelin's group BC in Sweden.

Among the fossils of the Tremadoc slates, there occur Trilobites of the genera *Dicellocephalus, Conocoryphe, Olenus, Cheirurus, Angelina, Asaphus;* also the *Lingulella Davisii* M'Coy, a Lingula-flags species. The Stiper Stones, quartzose strata in Shropshire, contain the burrows of Annelids (like *Arenicolites linearis* H.), which, however, are an uncertain mark of age. But beds in Arenig Mountain in Merionethshire, and the Skiddaw slates in the lake district of Cumberland, which are of the same age, have afforded over sixty species of fossils — among them, *Obolella plumbea* S., *Didymograptus geminus* Hisinger, *D. hirundo* Hisinger, *Ogygia Selwynii* S., *Æglina binodosa* S. and other species that are not Primordial, and are distinct from the species of the overlying Llandeilo flags (Lyell). H. A. Nicholson has announced that fourteen species of Graptolites, from the thirty-one in the Skiddaw slates, are species which Hall has described from the Quebec group of Canada (Q. J. G. Soc., xxviii. 217).

3. General Observations.

While the rocks of the Primordial era, over the larger part of North America, are chiefly sandstones, and but sparingly limestones, and bear evidence, in most places, of shallow waters and of currents bearing sediments, — those of this second period of the Lower Silurian are as prominently limestones, and over large regions are indications of clear seas. But, while limestones are the prevailing rock, all regions over the continent were not contemporaneously making lime-

stones. This is evident from the nature and distribution of the rocks. The sandy limestones of the Calciferous appear to mark in New York the transition from the Primordial (with its beach and sand-flat formations) to the second or Canadian period, while the limestone, along the Green Mountain range, if this is partly of the Chazy series, shows that the water deepened in that direction. In Newfoundland, on the other side of the same border region, the Calciferous epoch was a time of immense limestone accumulations, their thickness amounting to 3,200 feet; while, in the later part of the period, there were made as many feet of sandstones and shales, with little limestone. Again, over the Mississippi basin, — a region of deeper waters through a large part of geological history, and much of the time the southern half of an open "Mediterranean sea," connecting the Atlantic (or Mexican Gulf) and the Arctic Ocean, — the rocks are very largely limestones. Yet, even here, in some parts, sand-beds alternate at intervals with the limestones, showing changes during the period in the level of the sea-bottom or in the marine currents. Toward the head of the basin, and about Lake Superior, the prevalence of sandstones proves that the waters were there shallow, as Hall has remarked, and partly those of sea-shore flats and wind drifts. The events prove that no one kind of rock was formed simultaneously over a continent; but that the several parts of the continental seas were giving origin to different kinds, according to the depth of water, nearness to sea-shores, the character of the currents, and other circumstances.

Billings has observed, with regard to the Quebec formation, that the limestones of the era contain different fossils from the intervening shales; and yet both are essentially of the same age. The species of clear waters are often wholly unlike the contemporaneous species of muddy bottoms; and hence a change of condition, from that requisite for making limestones to that for shales, would naturally be accompanied by a change of species, and then be followed by a return of the former species, whenever (through some rising or sinking of the sea-bottom or land) the seas returned to their former clear condition.

Origin of the limestones. — The limestones of New York and Canada contain various fossils, and may have resulted from the trituration of shells, crinoids, etc. If so, the species must have lived in comparatively shallow water, like those making the shell banks or coral reefs of the Pacific; for the waves and currents are the pulverizing agents, and these, at great depths, are too feeble for such work.

The Lower Magnesian limestones of the Mississippi basin contain

very few fossils. It is possible that these limestones were largely made from the minute shells of Rhizopods; and, if so, they may have been accumulated in deep water.

3. TRENTON PERIOD (4).

1. American.

Epochs. — 1. Trenton epoch (4 *a*), or that of the Black River and Trenton limestones. 2. Utica (4 *b*), or that of the Utica shale. 3. Hudson River (4 *c*), or that of the Hudson River group and the Cincinnati limestones and shales.

I. Rocks: kinds and distribution.

The earlier part of the Trenton period was eminently a limestone-making era. A broad limestone belt of this era stretches across Central New York, north of the Mohawk (4 *a*, on map, p. 165), and extends westward through Canada to Wisconsin (where it includes the "Galena limestone"), and into Minnesota; it occurs also in Missouri and in central Tennessee. It stretches northwest of Lake Superior in a broad band west of the Archæan, passing Winnipeg Lake. It makes part of the crystalline limestone of the Green Mountains, as identified by Trenton fossils in Vermont, and in Columbia and Dutchess Counties, N. Y., where Trenton fossils occur; and is also extensively developed in the Eastern Appalachians, south of New York.

In the State of New York it constitutes the high bluffs of the gorge at Trenton Falls, on West Canada Creek, and thence derived its name. It occurs in the Ottawa region in Canada, and extends northeastward to Quebec.

The formation in New York is divided into the *Black River* and *Trenton* limestones, the latter being the upper; and these divisions are recognized in Canada and some parts of the States west of New York. The lower part of the Black River limestone is distinguished by the New York geologists as the *Birdseye limestone*, from crystalline points scattered through the rock.

The thickness of the series in northern New York and Canada, where probably lay the ocean's border, is generally from 100 to 300 feet; yet, in the region of Ottawa — a great St. Lawrence Bay in the earlier Silurian era (see map, p. 165) — it is about 800 feet. West of the Appalachians, the thickness averages about 300 feet. Along the Appalachian region in Pennsylvania, it is made 2,000 feet by Rogers.

The *Utica shale*, or the rock of the Utica epoch, is the surface-rock along a narrow region in the Mohawk valley, New York (see 4 *b* on map, p. 165), following a course nearly parallel with the outline of

the Archæan farther north. The shale is in some places three hundred feet, or more, thick. It extends westward through Canada, and beyond, probably into Wisconsin and Iowa, though a very thin deposit at the west; and also southward along the Appalachians, being, in Pennsylvania, from three hundred to seven hundred feet thick.

The rock is a crumbling shale, mostly of a dark blue-black or brownish-black color, and frequently bituminous or carbonaceous, — so much so, in certain places, as to serve as a black pigment. It sometimes contains thin coaly seams; and much money has been foolishly spent in searching for coal in this deposit. Thin layers of limestone are occasionally interpolated, especially in the lower part.

The rocks of the *Hudson River* epoch are shales in New York and Canada, but become calcareous to the west, and consist of limestone, largely mingled with shale, about Cincinnati, in Ohio, and farther west. The shales in New York (called *Hudson River* and *Lorraine* shales) cover a narrow area through the centre of the State, near the Mohawk, which widens toward the Hudson, and extends down the Hudson to Fishkill and Newburg; fossils have been found in them near Poughkeepsie. West of New York, the shales extend through western Canada, and southward of the State, along the Appalachians. The greatest thickness in Central New York is 1,000 feet. The Cincinnati limestone continues from Ohio westward, outcropping in several of the States of the Mississippi valley.

Limestone of this epoch occurs on the Island of Anticosti, in the Gulf of St. Lawrence, about 1,000 feet thick.

The slates of the Taconic Mountains of Western New England and the eastern border of New York, which include argillyte, hydromica, mica, and chlorite schists, being increasingly crystalline to the southward, are underlaid by the crystalline limestone adjoining; and it has been proved by fossils, both in Vermont and in New York, that the limestone adjoining the slates is in part Trenton. The slates are Hudson River. These "Taconic slates" are continuous with the Poughkeepsie slates above referred to. (See beyond, p. 212.)

1. **Trenton Epoch.** — (*a.*) *New York and to the Eastward.* — In New York, the Trenton limestone is grayish-black to black. It is sometimes bituminous, especially in its upper portions. Its layers are often thin, and beds of shale in many places intervene. The black color is due to carbon or carbonaceous substances, as is shown by its burning white. The crystalline points of the Birdseye are not always present, and occur in other limestones. The color of this rock is drab or dove-colored and brownish, and not so dark as that of the overlying beds. The Black River limestone is named from Black River, N. Y., east of Lake Ontario. The color is generally dark, nearly black.

In Canada, the Trenton outcrops over a large area about Ottawa, and also over another of less width along the north side of the St. Lawrence, from Montreal eastward nearly to Quebec, and at intervals beyond to Murray Bay; and a branch passes southward from Montreal to Lake Champlain. Near Montreal, the whole thickness is 530 feet, and that of the lower part, including the Black River limestone and Birdseye limestone, 38 feet (Logan).

The Stockbridge limestone formation (Eolian limestone of Hitchcock) varies in thickness from 1,000 to probably 3,000 feet. In Mt. Eolus, East Dorset, Vt., the thickness is 2,000 feet. The upper part of this formation is doubtless Trenton, though its lower portion is referred to the Chazy epoch of the Canadian period.

(*b.*) *Interior Continental basin.* — The Galena or lead-bearing limestone, of Wisconsin and the adjoining States in the West, constitutes the upper portion of the Trenton series, and often alternates with layers of the Trenton limestone. Its color is light gray or yellowish. It is generally *magnesian* limestone. It is 100 to 200 feet thick in northern Illinois; about 250 feet thick near Dubuque, Iowa, and the underlying Trenton 20 to 100 feet (Hall). There is usually at base a buff-colored limestone, equivalent to the Black River group.

In Missouri, there are 350 feet of limestone, the upper 100 called *Receptaculite limestone* by Shumard.

In East Tennessee, the formation includes blue limestone, with many fossils, 200 to 600 feet thick; and, above, 380 feet of red and gray marble, 400 of bluish shale, and 250 of iron-limestone containing the *Asaphus Platycephalus.* In Middle Tennessee, where the beds are horizontal, there are from 400 to 450 feet of blue limestone (Safford).

(*c.*) *Arctic region.* — The Trenton limestone has been identified upon King William's Island, North Somerset and Boothia.

2. **Utica Epoch.** — (*a.*) *Interior Continental basin.* — The Utica shale is 15 to 35 feet thick at Glenn's Falls, in New York; 250 feet in Montgomery County; 300 in Lewis County; 300 near Quebec.

(*b.*) *Appalachian region.* — In Pennsylvania, the rock is a black shale, and in some parts it is fossiliferous. The thickness, given by Professor Rogers, in the Kittatinny, Nippenose, and Nittany valleys is 300 feet, and in the Kishacoquillas valley 400 feet.

3. **Hudson River Epoch.** — The Hudson River shales cover the region north of Lake Champlain, in Canada, reaching to Quebec, and northeastward to Montmorency and beyond. They also lie over a small area near the centre of the Trenton limestone region of the Ottawa basin.

In New York, the Hudson River beds include shales and sandstones. They are the *Lorraine shales* of Jefferson County (the *Pulaski shales* of the New York Annual Reports), containing some thin beds of limestone. The slates along the Hudson River were referred to the Quebec group by Logan, but are now proved to be mainly of this group.

The thickness of the shales, in Schoharie County, N. Y., is 700 feet; near Quebec, 2,000 feet; in western Canada, 700 feet; on Lake Huron, 180 feet; in the Michigan Peninsula, 18 feet; in Iowa, 25 to 100 feet. In Missouri, there are alternations of shale and sandstone, with some limestone, 100 to 200 feet in total thickness; at Cincinnati, shales and limestones, 700 feet thick. In Middle Tennessee, the Cincinnati series includes the Nashville group of Safford, and consists of argillaceous limestone, with many shaly layers, about 500 feet thick. In East Tennessee, the beds (corresponding to both the Utica and Hudson River epochs) are of great extent, and consist of blue calcareous and more or less sandy shales, with some thin layers of calcareous sandstone. They also occur of great thickness in Virginia, and reach down to Alabama.

In Pennsylvania, in the Kishicoquillas valley, the rock is a blue shale and slate, with some thin layers of calcareous sandstone, and the thickness is 1,200 feet; in the Nittany valley, 700 feet; in the Nippenose valley, a little less. (Rogers.)

The limestone formation on the island of Anticosti has a total thickness of nearly 2,400 feet, and is divided by Logan into five parts — the *first*, or lowest, 959 feet thick; the *second*, about 300 feet thick; the *third*, about 450 feet; the *fourth*, about 550 feet; the *fifth*, 70 feet. The first two are referred to the Trenton period, and the rest to the Upper Silurian. There are thin beds of shales in the series. The rocks are nearly horizontal.

II. Economical Products.

The Galena limestone, of Wisconsin and the adjoining portions of Illinois and Iowa, is noted for its yield of lead ore. The ore is the ordinary sulphid of lead, or *Galenite*. It occupies vast cavities, rather than veins, in the limestone, which cavities were filled from above.

The lead-region of Wisconsin and Illinois, according to Owen, is 87 miles from east to west, and 54 from north to south; and throughout much of this region traces of lead may be found. The beds resemble in position the lead-mines of Missouri; but the latter occur in a limestone of the Calciferous epoch. These mines of the Upper Mississippi have been the subject of a report (1854) by J. D. Whitney. The galenite is often in large crystals, and is associated with sphalerite (zinc blende or "black jack"), Smithsonite (carbonate of zinc), pyrite, and marcasite, and occasionally barite (heavy spar), anglesite (sulphate of lead), chalcopyrite, azurite and zinc bloom. The Smithsonite (*dry-bone* of the miners) constitutes pseudomorphs at Mineral Point, Shullsburg, etc., in Wisconsin, after sphalerite and calcite. Beautiful stalactites of marcasite occur near Galena, at Marsden's Diggings.

Both the Trenton limestone and the Utica and Hudson River shales afford in some places mineral oil. It occurs sparingly in the Trenton, at Rivière à la Rosa (Montmorenci), in Canada; at Pakenham, Canada, in large Orthocerata; at Watertown, N. Y., in drops in fossil coral. In Kentucky, the blue limestone yields oil very abundantly. On Grand Manitoulin Island, Canada, a spring rises from the Utica shale; and another from the Hudson River beds at Guilderland, near Albany, N. Y.

The black Utica shale abounds in combustible material, although containing no coal. Whitney found about 21 per cent. in the shale of Savannah, Ill.; 11 to 16 per cent. in that of Dubuque; and 12 to 14 per cent. in that of Herkimer County, N. Y.

The Trenton formation in East Tennessee affords a *reddish variegated* marble of great beauty, and also a *grayish-white* variety, which are extensively worked and exported.

III. Life.

1. *Plants.*

Sea-weeds are the only known fossil plants, and specimens are rare. Two of the species are represented in Figs. 316 B, C.

Fig. 316 B is the *Buthotrephis gracilis* H., and Fig. 316 C, *B. succulosus* H. The figures represent only portions of these plants.

Remains of land plants have been announced as occurring in beds of the Hudson River group in Ohio and Kentucky by Lesquereux; and Figs. 316 D, E, F, represent three of the species named by him. One (316 E), from near Cincinnati, is supposed to be related to the Ground Pine, or Lycopods; another is a Fern (316 F) from the

same rock at Covington, Kentucky, the specimen being a small portion of a frond; and the third (316 F), from near Cincinnati, is a section of a stem resembling that of a Sigillarid or Lepidodendrid, the markings of the surface being the scars left by the fallen leaves.

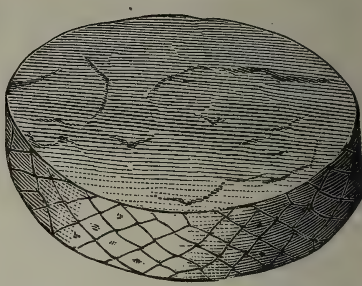
Fig. 316 B.

Fig. 316 C.

Fig. 316 D.

Fig. 316 E.

Fig. 316 F.



Algæ. — Fig. 316 B, Buthotrephis gracilis; 316 C, B. succulosus. Land Plants. — 316 D, Psilophytum gracillimum; 316 E, Sphenophyllum primævum; 316 F, Protostigma sigillarioides.

2. *Animals.*

1. Trenton Epoch.

The seas of the Trenton period were densely populated with animal life. Many of the beds are made of the shells, corals, and crinoids, packed down in bulk; and most of the less fossiliferous compact kinds have probably the same origin, and differ only in that the shells and other relics were pulverized by the action of the sea, and reduced to a calcareous sand or mud before consolidation; while others may be of Rhizopod origin.

The same four sub-kingdoms of invertebrate animal life were represented as in the preceding period, by marine species. All the grander subdivisions of the Radiate and Molluscan sub-kingdoms had their species. The Articulates were still confined to the inferior aquatic classes of Worms and Crustaceans.

Among RADIATES, there were now undoubted Corals (Figs. 317, 318), of the class of *Polyps*, as well as *Crinoids* (Figs. 324, 325), increasing much the diversity and beauty of the flowers of the seas — the only flowers of the Paleozoic world. There were, however, but few Polyp-corals, compared with the number in later periods. Single masses of the coral *Columnaria alveolata* H. (Fig. 318) occur in the

Figs. 317–325.

RADIATES. — Fig. 317, Petraia corniculum ; 318 *a*, Columnaria alveolata ; 319, 320, Chætetes lycoperdon ; 321 *a*, Graptolithus amplexicaulis ; 322, Palæaster matutina ; 323, Tæniaster spinosa ; 324, Lecanocrinus elegans ; 325, Pleurocystis filitextus.

Black River limestone, weighing between two and three thousand pounds. Cystids (Fig. 325) were the most characteristic kind of Crinoids. They belong in geological history eminently to this early era, reaching in it their greatest expansion. The delicate plume-like forms of life called *Graptolites* were common (Fig. 321).

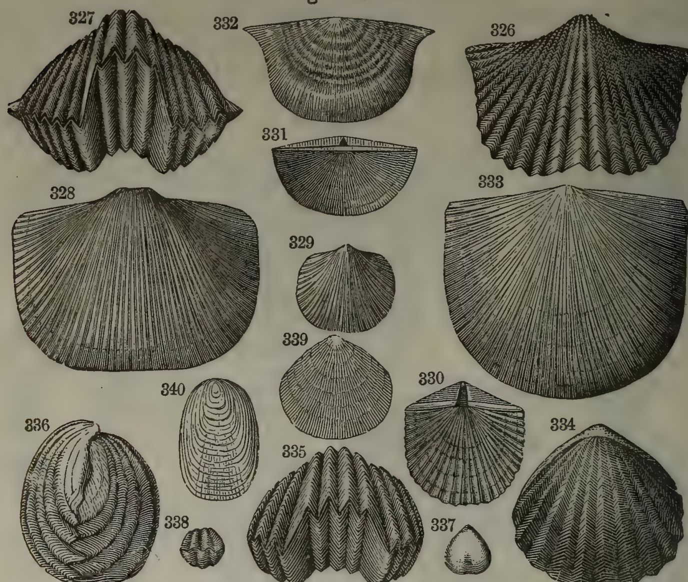
Brachiopods (Figs. 326–340), were yet the most abundant of MOLLUSKS, their shells outweighing and outnumbering those of all other species. But with these there were large numbers of each of the other classes, the *Bryozoans*, *Pteropods*, *Lamellibranchs* (Figs. 341–343), *Gasteropods* (Figs. 344–352) and *Cephalopods*.

Multitudes of delicate corals, made by Bryozoans, occur in tho limestone rocks.

The Trenton species of Brachiopods were mostly of the Orthis family (the genera *Orthis*, *Orthisina*, *Leptæna*, and *Strophomena*); and with these there were species of the *Lingula*, *Discina*, and *Rhyncho-*

nella groups, — the same families that were represented in the early Calciferous epoch. The genera *Rhynchonella*, which began in the era

Figs. 326–340.

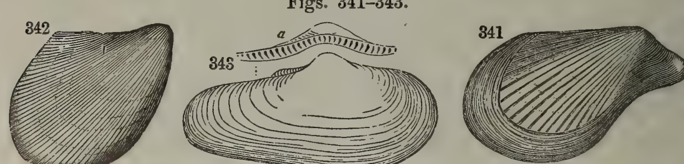


BRACHIOPODS — Figs. 326, 327, Orthis lynx; 328, O. occidentalis; 329, O. testudinaria; 330, O. tricenaria; 331, Leptæna sericea; 332, Strophomena (Leptæna) rugosa; 333, Stroph. alternata; 334, 335, 336, Rhynchonella capax; 337, 338, Rhynchonella (?) bisulcata; 339, Obolus filosus; 340, Lingula quadrata.

of the Quebec group, and *Crania* (Fig. 242), of the Trenton, have representatives in modern seas.

Orthocerata (Figs. 353–355), of the tribe of Cephalopods, were very numerous, and some were ten to fifteen feet long. Fig. 353 rep-

Figs. 341–343.

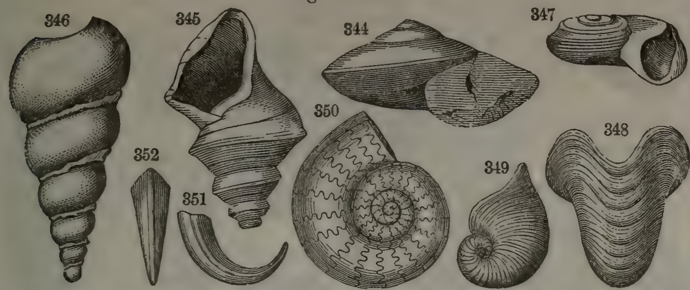


LAMELLIBRANCHS. — Fig. 341, Avicula (?) Trentonensis; 342, Ambonychia bellistriata; 343, Tellinomya nasuta.

resents a portion of one of these long conical (or *straight horn-shaped*, as the name signifies, p. 187) shells, and exhibits the partitions dividing it interiorly into chambers; and, in Fig. 353 *a*, one of

the partitions is figured separately, so as to show the position and size of the *siphuncle*. Fig. 355 is a transverse section of another

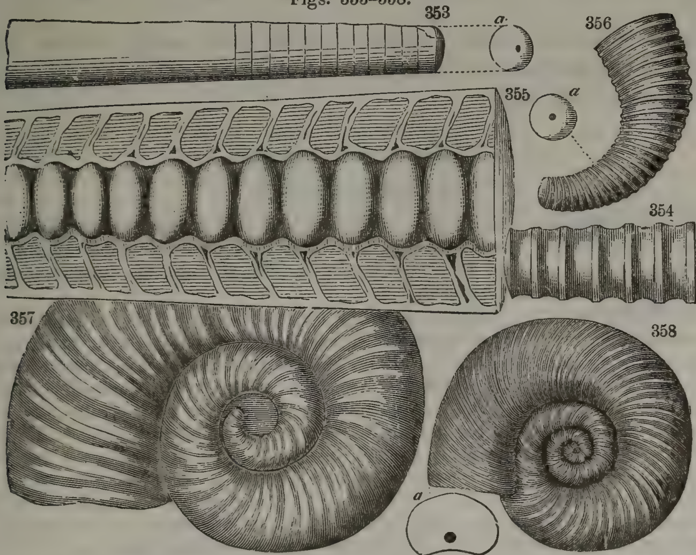
Figs 344–352.



GASTEROPODS.—Fig. 344, Pleurotomaria lenticularis; 345, Murchisonia bicincta; 346, M. bellicincta; 347, Helicotoma planulata; 348, 349, Bellerophon bilobatus; 350, Cyrtolites compressus; 351, C. (?) Trentonensis; 352, id., dorsal view.

species, in which the siphuncle is very large. These Orthocerata occupied the place of Fishes in the seas; yet, with their long unwieldy

Figs. 353–358.



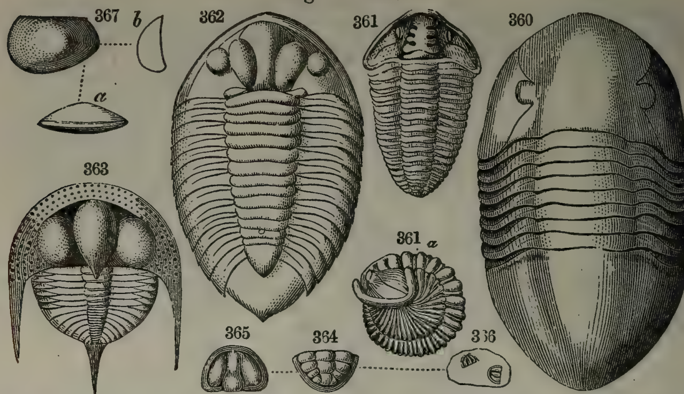
CEPHALOPODS.—Fig. 353, *a*, Orthoceras junceum; 354, O. vertebrale; 355, Ormoceras tenuifilum; 356, *a*, Cyrtoceras annulatum; 357, Cryptoceras undatum; 358, Trocholites Ammonius.

shells, they must have been sluggish animals. Other related Cephalopods had the shells coiled (Figs. 357, 358), a much more convenient

form; and these, although smaller species, were probably of superior rank to the *Orthocerata.*

Trilobites (Figs. 360–366), continued to be the most common and

Figs. 360-367.



CRUSTACEANS.—Fig. 360, Asaphus gigas (×⅓); 361, a, Calymene Blumenbachii; 362, Lichas Trentonensis; 363, Trinucleus concentricus; 364, 365, Agnostus lobatus (×4); 366, same, natural size; 367, a, b, Leperditia fabulites (natural size).

largest of ARTICULATES. Besides, there were many of the little bivalve Crustaceans or Ostracoids, the shell of one species of which is shown in Fig. 367.

Characteristic Species.

1. TRENTON EPOCH.

1. Protozoans. — *Sponges.* — *Astylospongia parvula* B. from the Trenton, near Ottawa City, Canada. Perhaps related to the Sponges, *Stromatocerium rugosum* H., Black River limestone; and *Receptaculites globularis* H., *R. Oweni* H., from the Galena limestone of Wisconsin and Illinois.

2. Radiates. — (*a.*) *Polyps.* — Fig. 317, *Petraia corniculum* H., a coral of the Cyathophyllum family, *P. profunda* H., Trenton limestone; *P. aperta* B., Black River limestone. Fig. 318, *Columnaria alveolata* H., Black River limestone, but occurring elsewhere in the Trenton, — a section of one of the columnar cells shows the tables or partitions of the interior; Fig. 318 *a*, top-view, showing the radiate cells; Fig. 319, *Chætetes lycoperdon* of the Trenton, a solid coral of a conoidal or hemispherical form, having a fibrous or fine columnar structure, as shown in the sectional view, Fig. 320. *Stenopora fibrosa* Goldf., is a common species; it began in the Calciferous, and continued into the Upper Silurian. The chain-coral (genus *Halysites*, a species of which is shown in Fig. 370) is occasionally found in the Trenton rocks, as in the Galena limestone, and in Canada. Fig. 372, *Tetradium fibrosum* Saff., Tennessee, Canada, a fine columnar coral with tubular quadrate cells; *T. columnare* H., Tenn.; *Aulopora arachnoidea* H.

(*b.*) *Acalephs.* — Fig. 321, *Graptolithus amplexicaulis* H. of the Trenton, of New York and Tennessee; 321 *a*, an enlarged view. The genera *Chætetes* (Fig. 319) and *Stenopora* have been referred to the Acalephs.

(*c.*) *Echinoderms.* — Fig. 322, the Star-fish *Palæaster matutina* H., of the Trenton:

323, *Tæniaster spinosa* B.; Fig. 324, the Crinid *Lecanocrinus elegans* B.; *Comarocystites Shumardi* M. & W., from Missouri; Fig. 325, the two-armed Cystid *Pleurocystis squamosus* B., of the Trenton, in Ottawa, Canada; also, *Agelacrinites Billingsii*, Chapman.

The number of Cystids described by E. Billings from the Lower Silurian of Canada is 21; making in all, for this era in North America, thus far known, 22; the Crinids of the same era amount to 50 species, and the Star-fishes to 11; 13 of the Crinids and 8 of the Star-fishes are Trenton species.

3. Mollusks. — (*a.*) *Bryozoans.* — Species of *Retepora* and *Ptilodictya* (related to Figs. 306, 307) are common; *Clathropora flabellata* H.

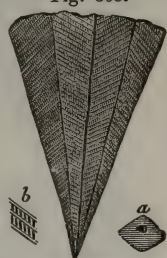
(*b.*) *Brachiopods.* — Figs. 326, 327, *Orthis lynx* Eich.; 328, *O. occidentalis* H.; 329, *O. testudinaria* Dalm.; 330, *O. tricenaria* Con.; 331, *Leptæna sericea* Sow.; 332, *Strophomena rugosa* H. (formerly *Leptæna depressa* Sow.; 333, *Stroph. alternata* Con.; 334–336, *Rhynchonella capax* Con.; 337, 338, *Rhynchonella* (?) *bisulcata* Emm.; 339, *Obolus filosus* (*Orbicula ? filosa* H.); 340, *Lingula quadrata* H., and other *Lingulellæ;* species of *Discina*, *Trematis*, *Camerella*, etc.

(*c.*) *Lamellibranchs.* — Fig. 341, *Avicula* (?) *Trentonensis* Con.; 342, *Ambonychia bellistriata* H.; 343, *Tellinomya nasuta* H.; also *Conocardium immaturum* B., of Black River limestone, Ottawa; species of *Modiolopsis*, *Cyrtodonta*.

(*d.*) *Gasteropods.* — Fig. 344, *Pleurotomaria lenticularis* Con., very common in the Trenton; also several other species of the genus; 345, *Murchisonia bicincta* McCoy; 346, *M. bellicincta* H., often four inches long; 347, *Helicotoma planulata* Salter, from Canada; *Ophileta Owenana*, M. & W., from the Galena limestone; 348, *Bellerophon bilobatus* Sow. — very common; 349, same, side-view; 350, *Cyrtolites compressus* H.; 351, 352, *Cyrtolites* (?) *Trentonensis* H. The genus *Cyrtolites* is like a partly uncoiled Bellerophon, and is not chambered. The genera *Bellerophon* and *Cyrtolites* are supposed to belong to the group of *Heteropods.* There are also several Patella-like species of *Metoptoma* (formerly *Capulus* and *Patella*), a genus which began in the Calciferous beds; species of *Holopea*, *Cyclonema*, *Trochonema*, *Eunema*, *Raphistoma*, *Subulites*, etc. *Maclurea magna*, a Chazy species (Fig. 311, p. 191), occurs in the Trenton, in Middle Tennessee (Safford); *Chiton Canadensis* B. occurs in the Black River limestone, in Ottawa.

(*e.*) *Pteropods.* — Fig. 368 represents *Conularia Trentonensis* H., a delicate four-sided pyramid, apparently admitting of some motion at the angles, but having septa within in the smaller extremity (*a*); it is supposed therefore to be the shell of a Pteropod by Barrande; *b* is an enlarged view of the surface.

Fig. 368.



Conularia Trentonensis.

(*f.*) *Cephalopods.* — Fig. 353, *Orthoceras junceum* H., a small Trenton species; 354, *O. vertebrale* H., also Trenton, the figure reduced to one-third; 355, part of an *Ormoceras tenuifilum* H., common in the Black River limestone, and sometimes over two feet long: the genus *Ormoceras* is peculiar in the beaded form of the siphuncle. Other common species of the Orthoceras family are the *Endoceras proteiforme* H., and the *Gonioceras anceps* H. The *Endoceras* was in some cases fifteen feet long, and nearly one foot through. In this genus (named from the Greek κέρας, *horn*, and ἔνδον, *within*), there is a concentric structure of cone within cone. In *Gonioceras*, the partitions are much crowded and have a double curvature, and the siphuncle is central.

Among the curved species, Fig. 356 is *Cyrtoceras annulatum* H.; *a*, a transverse section; Fig. 357, *Cryptoceras undatum* (*Lituites undatus* H.), abundant in the Black River limestone; Fig. 358, *Trocholites Ammonius* Con., of the Trenton; 358 *a*, transverse section. In *Cryptoceras*, the spiral is open at the outer extremity, and the siphuncle is dorsal; while, in *Trocholites*, it is closed and tightly coiled throughout. *Lituites*, which first appeared in the Calciferous, differs from *Cryptoceras* in having the siphuncle sub-central. The genus *Phragmoceras* has the mouth of the shell very much contracted, by a bending inward of the sides; *P. immaturum* B., is from the Black River limestone of Canada.

4. Articulates. — (*a.*) *Worms.* — *Serpulites dissolutus* B., Trenton, of Montreal, etc., Canada; *Salterella Billingsii* Saff., Tennessee. (*b.*) *Trilobites.* — Fig. 360, *Asaphus platycephalus* (*Isotelus gigas*); the species is sometimes ten inches or a foot long; Fig. 361, *Calymene Blumenbachii* Brongt.; Fig. 361 *a*, same rolled up, by bringing the tail to the head, common; Fig. 362, *Lichas Trentonensis* B.; *L. cucullus* M. & W., from Illinois; Fig. 363, *Trinucleus concentricus* Eaton; Figs. 364, 365, *Agnostus lobatus* H., head and tail portions magnified; 366, natural size; *Illænus crassicauda* Wahl., New York and Illinois. Among the other species, occur the Genera *Bathyurus, Triarthrus, Cheirurus, Bronteus, Acidaspis, Dalmanites, Encrinurus, Harpes, Proëtus, Phacops;* of which, the first only is represented in the Primordial rocks. *Asaphus platycephalus* St. is the only trilobite common to the Chazy and Trenton (Billings).

(*b.*) *Ostracoids.* — Fig. 367, *Leperditia fabulites?* Con., natural size, from New York, Tennessee, etc.; *a*, *b*, transverse and vertical sections, the specimen from Canada (*L. Josephiana* Jones, who refers the species with a query to the *fabulites* of Conrad).

2. Utica and Cincinnati Epochs.

1. Radiates. — (*a.*) *Polyps.* — No corals have been described from the Utica shale. In the Hudson River beds in New York, there are species of *Chætetes* related to those of the Trenton, and rarely specimens of the *Favistella stellata* H. (Fig. 369), a columniform coral related to the *Columnariæ*, having stellate cells. This species is more abundant in the West. Cyathophyllids of the genus *Petraia* occur, as in the Trenton; also of the genus *Zaphrentis, Z. Canadensis* B.; also a species of the Chain-coral, or *Halysites, H. gracilis* H., Fig. 370, from Green Bay, Wisconsin; also *Syringopora obsoleta* H. (Fig. 371); and species of the genus Tetradium, as *Tetradium fibrosum* Saff., Figs. 372, 372 *a; Aulopora arachnoidea* H.

Figs. 369–373.

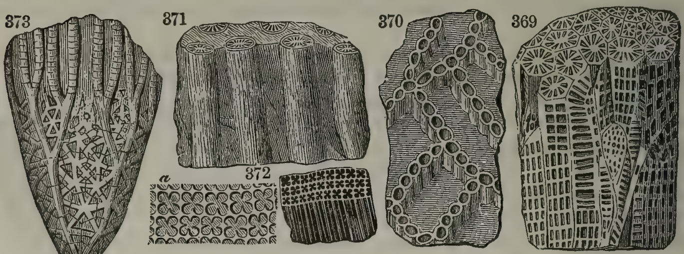
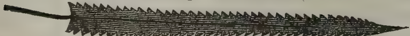


Fig. 369, Favistella stellata; 370, Halysites gracilis; 371, Syringopora obsoleta; 372, *a*, Tetradium fibrosum; 373, Glyptocrinus decadactylus.

(*b.*) *Acalephs.* — Fig. 374 represents the *Graptolithus pristis* H., a species occurring abundantly in the Hudson River and Utica shales at many localities. Several other species have been described by Hall.

(*c.*) *Echinoderms.* — Crinids, Cystids, and Star-fishes occur in the rocks of the period. Among Crinids, the *Glyptocrinus decadactylus* H. (Fig. 373) is not uncommon, occurring in New York, Ohio, Kentucky and other States; also species of the genera *Dendrocrinus, Palæocrinus, Heterocrinus, Hybocrinus, Porocrinus*, etc. Fig. 375 represents a large Star-fish from the Blue limestone of Cincinnati, as figured by U. P. James, the original of which was four inches across.

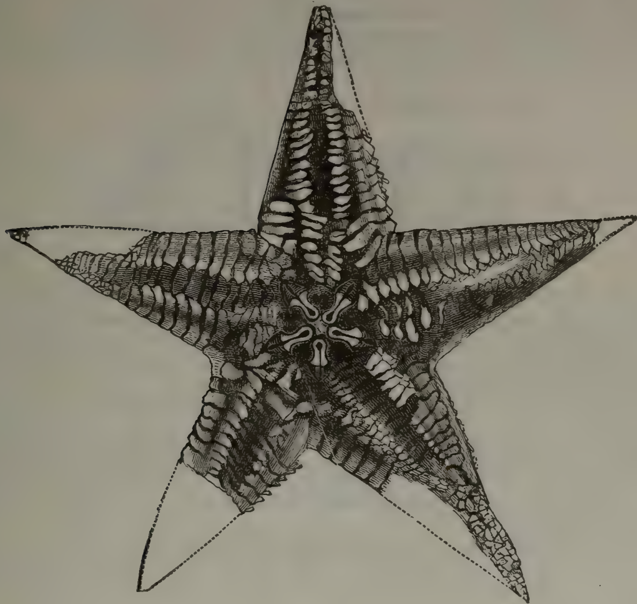
Fig. 374.



Graptolithus pristis.

2. Mollusks. — The Trenton Brachiopods *Leptæna sericea* Sow., Fig. 331; *Strophomena alternata* Con., Fig. 333; *Orthis testudinaria* Dalm., Fig. 329; *Orthis lynx* Eichw., Fig. 326; *Orthis occidentalis* H., Fig. 328; *Rhynchonella capax* Con., Figs. 334–336; and some others, are continued in the Cincinnati epoch; also the Heteropod *Bellerophon bilobatus*, Figs. 348, 349; the Gasteropod, *Murchisonia bicincta* H.; the

Fig. 375.



Echinoderm. — Palasterina (?) Jamesii.

Cephalopods, *Trocholites Ammonius* Con., Fig. 358, and species of the Orthoceras family, etc. The following are characteristic species: Lamellibranchs, *Pterinea demissa* M'Coy,

Figs. 376–379.

Lamellibranchs. — Fig. 376, Pterinea demissa; 377, Ambonychia radiata; 378, Modiolopsis modiolaris (×⅔); 379, Orthonota parallela.

Fig. 376; *Ambonychia radiata* H., Fig. 377; *Modiolopsis modiolaris* Con., Fig. 378; *Orthonota parallela* H., Fig. 379; *Cyrtodonta Hindi* B.; *Dolabra Sterlingensis* M. & W.,

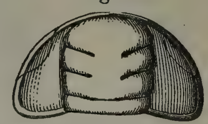
from the Cincinnati group. Among Gasteropods, occur *Cyrtolites ornatus* Con., near Fig. 350; *C. imbricatus* M. & W., Illinois; *Cyclonema bilix* Con., *Pleurotomaria Americana* B.

Among Pteropods, there are species of *Tentaculites*, *T. tenuistriatus* M. & W., and *T. Oswegoensis* M. & W., from Illinois, in the Cincinnati group.

3. Articulates. — Among Trilobites, *Asaphus platycephalus* (Fig. 360), *Calymene Blumenbachii* Brngt. and *Trinucleus concentricus* (Fig. 363) continue on from the Trenton period; but *A. platycephalus* is rivalled both as to abundance and size by *A. megistos*, already referred to, found in Ohio and other States west. *A. Canadensis* Chapm. is a species from the Utica shale. *Triarthrus Beckii* is common in the Utica shale, and occasionally seen in the Trenton beds. The head-shield generally occurs without the body: Fig. 380

Fig. 380.

Fig. 381.



Triarthrus Beckii.

represents its usual form, and Fig. 381 the same entire. The body is much like that of a *Calymene* (Fig. 361): it has a row of minute spines along the middle of the back.

The Anticosti limestone is supposed to range in time from the Trenton period through the Niagara, and probably through the Lower Helderberg. Some of the characteristic fossils of its upper four divisions (p. 196) are the following.

I. *Leptæna sericea*, *Strophomena rhomboidalis*, *S. pecten* Sharpe, *Orthis lynx*, *O. Salteri* B., *Pentamerus reversus* B., *Bellerophon bilobatus*, *B. acutus* Sharpe, *Pleurotomaria Americana* B., *Ambonychia radiata;* and, with these, *Halysites catenulata*, *Favosites Gothlandica* Linn, *Petraia gracilis* B., a *Heliolites;* also *Strophomena subtenta* Con., a species occurring in the Cincinnati limestone, and *S. recta* Con., a Wisconsin (Mineral Point) species.

II. *Favosites Gothlandica*, *Halysites catenulata*, *Stromatopora concentrica*, a species of *Aulopora*, species of *Cyathophyllum*, *Orthis Salteri*, *Strophomena Leda*, *S. pecten*, *Pentamerus Barrandei* B., *Atrypa congesta* Con., *A. reticularis* Linn., *Calymene Blumenbachii*, etc.

III. The same species as in II. of *Favosites*, *Halysites*, *Stromatopora*, *Strophomena*, *Atrypa*, *Orthis*, *Calymene*, with *Orthis elegantula* Dalm., *Stricklandinia lens* Sow., *Pentamerus oblongus* Sow. (a species characteristic of the Clinton group in the Niagara period), *Phacops orestes* B., *Favosites favosa* H. Niagara species), *Zaphrentis Stokesi* B., *Alveolites Labechii* M'Edw., etc.

IV. The same species as in III. of *Favosites*, *Halysites*, *Stromatopora*, *Zaphrentis*, *Alveolites*, *Strophomena*, *Atrypa*, *Orthis*, *Calymene*, *Phacops*, with species of *Cyathophyllum*, *Ptychophyllum*, etc.

2. European.

In Great Britain, the beds of the whole Lower Silurian from the bottom of the Primordial make a single conformable series. Those which appear to be equivalents of the beds of the Trenton period are the Llandeilo flags, 5,000 feet thick; the Bala beds, or Caradoc rocks, 6,000 feet, and the Lower Llandovery, 1,000 feet. The Llandeilo flags of South Wales include thin laminated sandstones or flags, and dark earthy slates often gritty, with some beds of limestone. These pass up, without any definite line of demarcation, into the Bala

rocks, which also include flags and slates, but the latter in general more sandy, with beds of limestone. In the whole thickness of 6,000 feet, there are two beds of limestone, one, of little persistency, the Hirnant limestone, of 10 feet, and the other the Bala, of 25 feet; and besides, 1,400 feet below the latter, there is a Bala "ash-bed" of 15 feet thickness. Many beds of igneous rocks are intercalated in some regions. In Shropshire, corresponding beds are sandstones, with occasional calcareous layers — the Caradoc sandstone of Murchison.

Near the town of Llandovery in South Wales, there is a series of beds of sandstone and shale, called the Lower Llandovery, which are referred to the Lower Silurian.

In Bohemia and Bavaria, the Lower Silurian rocks are schists, quartzytes, and conglomerates, the lower part of Stage D of Barrande; in Scandinavia, there are limestones overlaid by slates and flags; in Russia, in the Baltic provinces, mainly limestones; in Spain, schists and limestones, with some sandstones.

The following list of characteristic fossils of the Lower Silurian of Great Britain serves to show the close parallelism in the life of this era between Europe and America. The names of species that occur also in North America are printed in small capitals.

PROTOZOANS. — *Sponges*, species of *Acanthospongia* and *Clione; Stromatopora striatella* D'Orb.

RADIATES. (1) *Polyp-corals: Favosites alveolaris* Goldf., F. GOTHLANDICA, two species of *Heliolites*, HALYSITES CATENULATA, *Petraia subduplicata* M'Coy, *Syringophyllum (Sarcinula) organum* Linn. (2) *Acalephs:* ALVEOLITES (STENOPORA) FIBROSA, same, variety LYCOPERDON, *Ptilodictya dichotoma* Portl., various Graptolites, of the genera *Diplograptus, Phyllograptus*, etc. (3) *Echinoderms: Glyptocrinus basalis* M'Coy, two species of *Palæaster*, id. of *Sphæronites* and *Echinosphærites*, *Agelacrinites Buchianus* Forbes.

MOLLUSKS. — (1) *Bryozoans: Fenestella antiqua*, PTILODICTYA ACUTA H., *P. dichotoma*, *Retepora Hisingeri.* — (2) *Brachiopods: Lingula Davisii*, ORTHIS TESTUDINARIA, O. VESPERTILIO Sow., O. FLABELLULUM Sow., Fig. 388. O. CALLIGRAMMA Dalm., O.

Figs. 388–394.

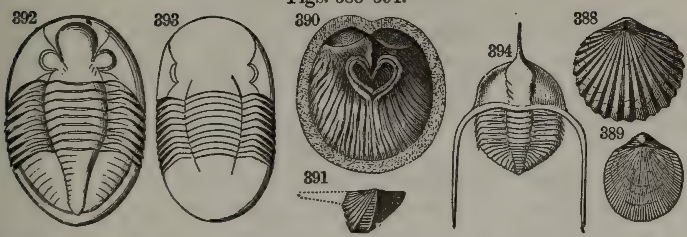


Fig. 388, Orthis flabellulum: 389, O. elegantula; 390, Crania divaricata; 391, Conocardium dipterum; 392, Asaphus Powisii; 393, Illænus Davisii; 394, Ampyx nudus.

ELEGANTULA, Dalm. (Fig. 389), O. BIFORATA (or LYNX, Fig. 326), O. STRIATULA Con., O. PORCATA, *Strophomena complanata* Sow., LEPTÆNA SERICEA (Fig. 331), *Crania divaricata* M'Coy (Fig. 390), *Discina (Trematis) punctata* Sow. (near *T. cancellata* Sow., of the Trenton). — (3) *Lamellibranchs:* MODIOLOPSIS MODIOLARIS, *M. expansa* Portl.,

Ctenodonta varicosa, ORTHONOTA NASUTA Con., *Conocardium dipterum* S. (Fig. 391), *Ambonychia Triton.* — (4) *Pteropods* and *Heteropods:* THECA TRIANGULARIS Portl., *T. vaginula* S., *Ecculiomphalus Bucklandi* Portl., *Bellerophon carinatus* Sow. — (5) *Gasteropods:* MACLUREA LOGANI S.? (Scotland), *Murchisonia simplex* M'Coy, *Holopea concinna* M'Coy. — (6) *Cephalopods: Orthoceras vagans* S.; *Lituites Hibernicus* S.; *Cyrtoceras inæquiseptum* Portl., C. MULTICAMERATUM H.?

ARTICULATES. — (1) *Worms: Nereites Sedgwickii* Murch., *Tentaculites Anglicus* S. (2) *Trilobites: Ogygia Buchii* Brngt., *Asaphus tyrannus* Angelin, *A. Powisii* Sharpe (Fig. 392), TRINUCLEUS CONCENTRICUS, CALYMENE BLUMENBACHII, *Illænus Davisii* S. (Fig. 393), *Ampyx nudus* Murch. (Fig. 394), *Lichas Hibernicus* Portl., *Agnostus pisiformis* (also Primordial), and also species of *Harpes*, *Phacops*, *Cheirurus*, *Cybele*, etc. — (3) *Ostracoids: Beyrichia complicata.*

The Lower Llandovery rocks contain STRICKLANDINIA (Pentamerus) LENS*, and rarely PENTAMERUS OBLONGUS*, both species occurring in the Anticosti beds, also *Pentamerus undatus* Sow., *Meristella angustifrons* M'Coy, *M.? crassa* Sow., ATRYPA RETICULARIS*, *A. crassa*, *Orthis calligramma**†, O. ELEGANTULA*†, *O. virgata*, STROPHOMENA DEPRESSA*†, LEPTÆNA SERICEA*†, L. TRANSVERSALIS*†, *Murchisonia simplex*, *Bellerophon dilatatus* Sow.*†, *Petraia subduplicata**†; *Illænus Bowmanni* S.†, CALYMENE BLUMENBACHII*†, *Lichas laxatus* M'Coy†, *Homalonotus sulcatus*†. FAVOSITES GOTHLANDICA*†, HELIOLITES INTERSTINCTA*†, HALYSITES CATENULATA*†. The species whose names are marked with a † occur also in the formations below; and those with an * are found also in the Upper Silurian. A species of *Eozoon* has been reported from the green serpentine marble of Connemara, of the age of the Lower Silurian according to Murchison, it underlying the Lower Llandovery beds.

Rhizopods have been found by Ehrenberg in the Obolus or Ungulite grit of Russia. The rock is in part a very soft green-sand; and the connection of the microscopic Rhizopod shells with the green grains shows, as Ehrenberg states, that it is of the same nature with the Green-sand of the Cretaceous. Among these fossils, occur the three modern genera *Textularia*, *Rotalia*, and *Guttulina*. Ehrenberg has also detected in this rock great numbers of Pteropods (related to *Hyolites*), and made out ten new species and four genera. The rock derives its name from its most common fossil, *Obolus Apollinis* (Fig. 246, p. 173), which is about as large as a small finger-nail. The *Siphonotreta unguiculata* (Fig. 245) is another of its fossils. It has also afforded minute teeth, not larger than pins' heads, which Pander regarded as those of Ganoids, but which have since been shown to be from the dental apparatus of Mollusks. The age of the beds is either that of the Trenton or earlier. They underlie a dark-colored schist containing graptolites, and over this occurs the Orthoceratite limestone or *Pleta.*

General Observations.

North American Geography. — The era of limestone-making, — and, therefore, of continental seas largely free from sediments, — which made progress in the Canadian period, reached its culmination in the earlier division of the Trenton period, when limestones were almost the only kind of rock being deposited over the breadth of the continent. The absence of sediments from a large part of the continental region must have been owing to the absence of the conditions on which their distribution depends. The currents of the ocean which ordinarily swept over the land (the Labrador current from the north, along the eastern border, and the Gulf Stream from the south, over the interior), must have had their action partly suspended. This may have been caused by a barrier outside of the limestone area, near or outside of the present Atlantic coast line. If the land, in the shallow

region outside of the present Atlantic border of the continent, were above tide-level at the time (see p. 422), it would have been a continental barrier against both waves and currents.

With the opening of the Hudson River era, sediments again were deposited over New York and the Appalachians, and some change of level had, therefore, taken place. But, as the formation of limestones was continued in the Mississippi basin, and also in the St. Lawrence bay (at Anticosti), the change did not affect essentially these regions. If the Atlantic barrier, above alluded to, were a fact in the Trenton era, an oscillation of level submerging it, and raising toward the surface another parallel region more to the west, where the Appalachians now stand, would have opened again the New York and Appalachian area to the ocean, and so might have occasioned the transition to sedimentary accumulations.

Climate. — No proof that a diversity of zones of climate prevailed over the globe is observable in the fossils of the Trenton period, or of any part of the Lower Silurian era, so far as yet studied. The following species, common in the United States, and occurring at least as far south as Tennessee and Alabama, have been found in the strata of northern North America, near Lake Winnipeg: *Strophomena alternata*, *Leptæna sericea?*, *Maclurea magna*, *Pleurotomaria lenticularis?*, *Calymene senaria*, *Chætetes Lycoperdon*, *Receptaculites Neptuni*.

The mild temperature of the Arctic regions is further evident from the occurrence of the following United States and European species on King William's Island, North Devon, and at Depot Bay, in Bellot's Strait (lat. 72°, long. 94°), — *Chætetes lycoperdon*, *Orthoceras moniliforme* H., *Receptaculites Neptuni* De France, *Ormoceras crebriseptum* H., *Huronia vertebralis* Stokes; besides *Maclurea Arctica* Haughton, near the Chazy species *M. magna*. Moreover, the formation of thick strata of limestone shows that life like that of lower latitudes not only existed there, but flourished in profusion.

Life. — Exterminations. — At the close of the Chazy epoch, its species, with few exceptions, disappeared, for the rocks of the Trenton epoch contain a different range of species. No facts have been observed to explain the nature of the catastrophe that intervened between the two epochs. Such a fact as this — that sinking the coral islands of the Pacific three hundred feet would destroy the reef-forming Corals of those islands — may have some bearing on the subject. The geographical changes introducing the Hudson River epoch appear to have had some connection with the partial destruction of the Trenton species that then occurred. A large number of species are continued on from the Trenton into the Cincinnati group, wherever the rocks of the latter, like those of the former, are limestones. But,

where the latter are shales, — in other words, where the seas afterward had a muddy bottom, — there the species were almost wholly different, and the new fauna was one fitted for the muddy bottom, including, therefore, many Lamellibranchs with the Brachiopods, and but few Crinoids.

4. GENERAL OBSERVATIONS ON THE LOWER SILURIAN.

Thus far in American Geology, no evidence has been detected of (1) fresh-water lakes or deposits, or (2) of terrestrial or fresh-water animal life. The animals were mainly Protozoan, Molluscan, and Radiate, because these are the aquatic divisions of the animal kingdom; and with them were associated the aquatic Articulates, — Worms and Crustaceans; but not yet the aquatic Vertebrates, — Fishes. Terrestrial animal life may have existed, but no trace of it has yet been found. The continent was already outlined, and, in its heavings and progressing changes, its coming features were shadowed forth, — even its mountain chains, the wide interior basin and the great lakes, — although the mountains had yet but small parts above the seas, and the lakes only the beginnings of their depressions.

1. Differences in the conditions of the several continental regions of North America. — (*a.*) *Reality of the Eastern Border region in American geological history.* — In the Primordial and Canadian periods, the thickness of the limestone strata made in the Newfoundland seas was far greater than that over the Continental Interior. And, during the Hudson River epoch, when fragmental rocks were forming over New York, a limestone formation commenced in Anticosti, which continued in progress through a large part of the Upper Silurian, with no break at the close of the Lower Silurian. Such facts sustain the statement, on page 145, that the Eastern Border region — including central and eastern New England, and the British possessions on the north to Labrador and Newfoundland — was an area of progress independent of that of the great mass of the continent.

(*b.*) *The formations thicker in the Appalachian region than over the Continental Interior.* — The whole thickness of the Lower Silurian in Missouri was 2,000 feet; in Iowa, 1,200; in Illinois, but 700; in Middle Tennessee, 1,000 feet, where the outcrops, however, expose nothing below the top rocks of the Canadian period. On the contrary, in the Appalachian region (which includes the whole mountain region from Quebec to Alabama), the thickness in Pennsylvania was 12,000 feet (Rogers); in the Green Mountains, not less; in Canada, north of Lake Champlain and Vermont, at least 7,000 feet; in East Tennessee, 15,000 feet, or more.

(*c.*) *Proportion of limestones to the sandstones and shales less in the*

Appalachian region and to the north, than over the Interior basin. — Out of the whole thickness of the rocks in Missouri and Illinois, five-sixths are limestone, and in Iowa, one-half. In the Appalachian region, out of the 12,000 feet, 5,000 feet, or five-twelfths, are limestone, according to Rogers; in Tennessee, at least one-third; in Canada, about Quebec, not one-twentieth.

(*d.*) *The Appalachian region, the Green Mountains included, from the period of the earliest Silurian, a region of comparatively shallow waters.* — Along its course, there were Archæan islands and reefs, when the Silurian era opened, — portions of the Blue Ridge to the south, the Highlands of New Jersey and Orange and Putnam Counties, N. Y., and the patches of Archæan rocks in New England being some of these areas. It was hence a barrier region to the continent, over which the Atlantic currents flowed and waves broke; and here, therefore, fragmental rocks — rocks of sand, pebbles, mud, and clay — ought to have abounded. The interior Continental basin, under the protection of this barrier, was occupied by relatively quiet seas, and fitted thereby for the growth of Crinoids, Corals, and Mollusks, whose calcareous relics were the material of the limestones. This point is illustrated by nearly all the successive formations.

2. General quiet of the Lower Silurian era; Limited disturbances. — The strata of the Lower Silurian in North America appear to have been spread out over the Interior Continental basin in horizontal beds of great extent, and to have followed one another without much disturbance of the formations. There were extended oscillations of the surface of the continent; for this is indicated in the varying limits of the formations, as well as the alternations in the kinds of rocks.

One marked exception to the general quiet occurred during some part of the Canadian period, in the region of Lake Superior, where there were extensive igneous ejections (p. 185). Another case of disturbance has been noted in Newfoundland (p. 182). But still it remains a fact that the Lower Silurian was an era of comparative quiet. This quiet, moreover, was a long one, — probably *as long as all of the time that has since elapsed.*

5. DISTURBANCES AT THE CLOSE OF THE LOWER SILURIAN.

The long quiet was finally interrupted, in some parts of the continent, by subterranean movements and metamorphism, — not by sudden catastrophe, but, after the ordinary style in geological progress, by slow and gradual change. The principal regions of this change, now known, are that of the Green Mountains, the northern extremity of the Appalachian region, and that of the "Cincinnati uplift," from Lake Erie, over the Cincinnati region, into Tennessee.

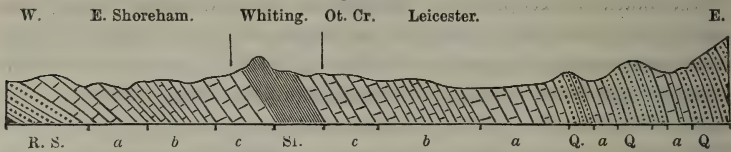
During Paleozoic time, previous to the epoch of revolution, the Green Mountain area had been a region of accumulating limestones, sand-beds, and mud-beds, and these lay in *horizontal* strata, making a series of great thickness, — the actual amount not yet ascertained. But here the rock-making over the region ended; next came the upturning, in which the same rocks were displaced, folded, and crystallized, and the Green Mountain region made dry land.

1. **The present position of the Rocks.** — The strata, originally horizontal, are now upturned, some portions standing vertical, the larger part inclined 30° to 60°, yet varying occasionally, at short intervals, from 10° to 90°, the beds rising and descending in great folds. Moreover, the whole series of beds, to the very bottom of the Silurian, were involved together in the upturning.

The following sections are from the region of the great crystalline limestone (or marble) of the Green Mountains, which extends from Vermont over Western Massachusetts and Connecticut, and part of Eastern New York. This region includes, west of its central line, the Taconic mountain range, of slate, mica schist, and other rocks, which lie between Massachusetts and New York. Over its eastern portion, and partly its central, there are ridges made chiefly of quartzyte, with hydromica and other schists; and one of these, near Bennington, Vermont, is 2,688 feet in height; other ridges consist of schists without quartzyte, the schists in Massachusetts and Connecticut comprising a coarse mica schist and gneiss.

Fig. 395 A, represents an east-and-west section fourteen miles long, through Whiting, Vermont, and shows the limestones (the blocked

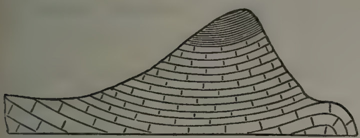
Fig. 395 A.



areas in the cut) standing at a high angle; on the west is the Red sand-rock (R. S.) of Potsdam age; *a*, *b*, *c*, are limestone strata of the Calciferous, Quebec group, and Trenton periods respectively, as proved by fossils discovered by Mr. A. Wing; next (Sl.) the slates of the Taconic belt; then limestones again, the stratum *c* affording Trenton or Chazy fossils, like that on the west of the slates; and at the east end, quartzyte (Q, the dotted areas), supposed to be the Potsdam sandstone, with limestone. The Taconic belt (Sl.) is here narrow and low, but southward it widens much. The Trenton limestone strata, *c*, *c*, along side of it, are really parts of one stratum folded either *over* or *under*

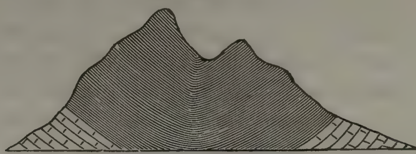
the folded-up slate, that is, lying either in an anticlinal or a synclinal. In other parts of the range, facts prove that the Taconic slates lie in a synclinal, the limestone passing underneath them. Fig. 395 B represents this condition in Mt. Eolus in Dorset, Vt. (Vermont Geol. Rep.), 3,148 feet in height; and Mt. Equinox and Spruce Peak are similar. Fig. 395 C, from Emmons, represents the same in Graylock, 3,505 feet

Fig. 395 B.



Mt. Eolus, Dorset.

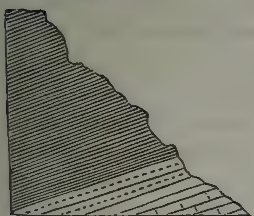
Fig. 395 C.



Graylock.

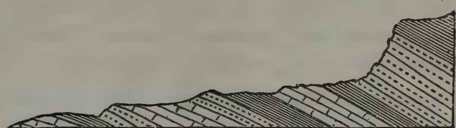
high, and it answers also for Mt. Washington, in southwestern Massachusetts, whose highest peak (Mt. Everett) is 2,634 feet high. Fig. 395 E exhibits alternations of limestone, quartzyte, and gneiss, on the east side of a small valley, four miles east of Great Barrington, Mass.; and 395 D, the same on the west side of the same valley; and ap-

Fig. 395 D.



West side of Konkaput Valley.

Fig. 395 E.



East side of Konkaput Valley.

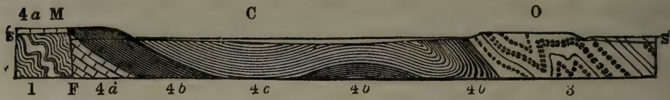
parently they are portions of a low anticlinal which spanned the valley. The above sections are sufficient to illustrate the upturned condition of the beds.

2. **The Crystalline Condition of the Beds.** — The limestones were once common fossiliferous limestones, as fossils in some localities prove; and the other rocks were sand-beds and mud-beds, partly fossiliferous. All are now crystalline; the limestones having been converted into white and clouded marbles, the quartzose sand-beds into quartzytes, and other sedimentary strata into clay slate (partly good roofing slate), hydromica schist, mica schist, chlorite schist, and gneiss and other rocks. The crystallization increases, though very gradually, from north to south, and from west to east, along the range.

3. **Extensive Fractures and Faults.** — Fractures and faults are many; but one fault had great extent. Fig. 395 F (from Logan)

shows the condition along it (at F) near the Falls of Montmorency (M), east of Quebec. On one side there is the Trenton limestone

Fig. 395 F.



(4 *a*), which is followed eastward by 4 *b* and 4 *c*, the Utica slate and Hudson River slates, and 3 the Quebec group; while on the other side there is Archæan gneiss overlaid horizontally by fifty feet of Trenton limestone. The fault is continued south-southwest through Vermont into Eastern New York. (Another section illustrating it, by Mr. Wing, and additional sections of the rocks of the limestone region, may be found in volumes xiii. and xiv. (1877) of the American Journal of Science.

4. **The Width of the Region Disturbed.** — On the west it extended to the Hudson; how far east is not ascertained, but possibly in some parts to the Connecticut. The map (Fig. 395 G) shows a portion from the more southern part of the region, spreading from Connecticut to the Hudson, in Dutchess County, N. Y. The limestone comes to the surface through folds or faults in *five* principal belts (besides others of less width), as exhibited on the map. The *Great Central belt, east* of the Taconic range, terminates against the Archæan in Putnam County. East of it there are two in Connecticut, separated by mica schist and gneiss; and two in Dutchess County, separated by mica schist, hydromica schist, and clay slate, passing south from the limestone belt *west* of the Taconic range. The directions of the strike and dip are indicated by the T-shaped symbols, the stem showing the direction of dip. Trenton fossils have been found in Ancram west of the Taconic range, and, farther southwest, along this more western limestone belt; and Hudson River fossils in the Poughkeepsie slates. As these slates and limestone are thus continuous with those of the Taconic mountain region, these fossils and those of Vermont show that the Taconic slates are of the age of the Hudson River group. (For a further statement of the facts, see American Journal of Science, xvii., 1879.)

5. **Other Effects of the Disturbance.** — Lake Champlain valley was probably defined before the Silurian era began, by Archæan uplifts along the Green Mountain area; but, if not, it dates from this epoch, as suggested by Logan. It lies where unstable or oscillating New England, through Lower Silurian time, hinged on to the stable Archæan; or, just where the heavy pressure during the era of disturbance operated against the stable Archæan, as it folded up the thick series of rocks to their bottom.

The great St. Lawrence gulf about Ottawa was probably nearly obliterated at this time; for no rocks later than Lower Silurian occur there until the Quaternary age, just before Man, excepting small

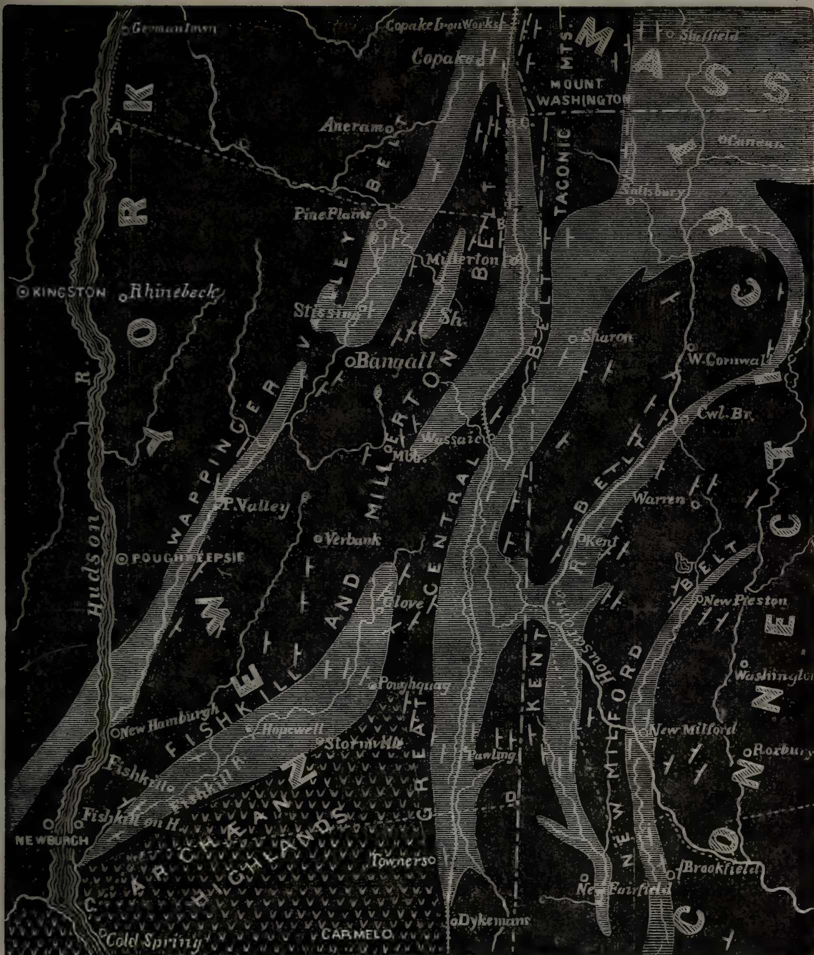


Fig. 395 G. — Map of part of Western New England and Eastern New York, showing the belts of limestone. AB, CD, north and south limits of Dutchess County, N. Y.; *B. C*, Boston Corners; *Cwl. Br.*, Cornwall Bridge; *Mbb.*, Mabbitsville; *P. Valley*, Pleasant Valley; *Sh.* Shekomeko. Scale 1-10th of an inch to a mile.

patches of Lower Helderberg near Montreal. Thus, the St. Lawrence channel, which was first a short strait between the Archæan areas of Canada and New York, had become much narrowed and lengthened

by the close of the Lower Silurian; but it still opened into a broad oceanic basin near the longitude of Quebec; for both Upper Silurian and Devonian strata, as has been stated, were formed over eastern Canada and part of New England.

6. **Time of the Epoch of Disturbance.** — This epoch is proved to have been between the Lower and Upper Silurian eras, as Logan first observed, by the fact that unaltered and unconformable Upper Silurian formations overlie in some places the upturned Lower Silurian beds; as near Gaspé, on the Bay of St. Lawrence; near Montreal, on St. Helen's Island and Belœil Mountain; at Becraft's Mountain, near Hudson, west of the Hudson River; in each of which cases the Lower Helderberg beds overlie unconformably Lower Silurian slates; and near Lake Memphremagog, where the Niagara limestone occurs with its characteristic fossils, and also beds of Devonian corals. Again, on the eastern side of the mountains, in the Connecticut valley, there are unconformable Lower or Upper Helderberg beds at Bernardston, Mass., and Littleton, N. H., which are evidence that the region extended here to the Connecticut. The earlier formations of the Upper Silurian are scarcely represented, or are very thin, in the *eastern* part of New York State, and this is apparently owing to the previous elevation of the Green Mountain region.

7. **Some Characteristics of the Force engaged.** — The cause of the extensive uplifts and flexures of the Lower Silurian rocks had the following characteristics: —

1. *The force acted at right angles to the course of the flexures.* — It is obvious, without explanation, that only force from this direction could have produced the result.

2. *The force acted from the direction of the ocean.* — For the effects are most intense to the eastward; they diminish toward the interior.

3. *The force was slow in action and long continued.* — This is evident from the regularity which the stratification now presents, notwithstanding the upturning; for there is no chaos: the beds remain in their old order, only bent into arches and bold flexures. The brittle rock experienced the force so gradually that it yielded with little fracture, except in the neighborhood of the axes of the folds, where the strain was greatest.

While all this upturning and crystallizing of strata was going forward in western New England, and displacements to the eastward even at Gaspé, there was comparative quiet north of Gaspé in the St. Lawrence Gulf; for the great limestone formation of Anticosti, which was begun in the Lower Silurian, continued its unbroken progress through the whole prolonged era of revolution, and afterward far into the Upper Silurian era.

It is not yet known that any portion of the Appalachians from New Jersey southwestward participated in the disturbances of this epoch. But, according to Safford, Newberry, and Orton, the region from Lake Erie over Cincinnati into Tennessee, where rocks of the Hudson River and Trenton eras are exposed to view, was then, for the most part, raised above the sea-level, and so remained, through the rest of the Silurian age and part of the Devonian, as an island in the continental seas. The axis of the uplifted region is parallel to that of the Appalachians. That this was the time of the uplift is proved by the absence of Upper Silurian and Lower Devonian beds over the region, these formations thinning out toward the axis; and, in Tennessee, as Safford states, by the Devonian black slate *resting directly* on the Lower Silurian beds. Over Kentucky, the uplift was less than in Tennessee or Ohio, and the area of it may have remained submerged. In Ohio, the region reaches Lake Erie between Sandusky and Toledo, and from there southwestward, it is marked, as Professor Newberry observes, by a distinct arch in the strata. The line of the axis presents now no conspicuous topographical feature; but the direction of the draining streams, which follow the strike of the strata on either side, indicates that it once formed a watershed that gave the initial bearing to their flow. The part of the arch about Cincinnati has been more deeply and extensively removed than farther north, though higher now than elsewhere, and, therefore, "this probably was originally the highest part of the arch within the limits of the State of Ohio."

In Europe, there was also a period of disturbance at the close of the Lower Silurian; but the destruction of life was less complete than over central North America, and corresponds nearly with that in the eastern basin about the Gulf of St. Lawrence.

There is evidence of unconformability between the Upper and Lower Silurian in many parts of England; and the elevation of the Westmoreland Hills, as first ascertained by Prof. Sedgwick, has been referred to this epoch; so, also, that of the mountains in North Wales, and hills in Cornwall, and the range of southern Scotland, from St. Abb's Head, on the east coast, to the Mull of Galloway. Elie de Beaumont refers to this era the elevation of the Hundsruck Chain (now about 3,000 feet high) and other ridges in Nassau. The changes of the period are supposed to have been attended in England by metamorphic action, in which gneiss and clay slates were made out of the Lower Silurian deposits.

B. UPPER SILURIAN.

Marine life, large oceans, small lands, and uniform climates — the features of the Lower Silurian — continued to characterize the opening period of the Upper Silurian.

The periods and epochs indicated in the New York rocks have been mentioned on p. 164. The periods are — the NIAGARA (5), the SALINA (6), and the LOWER HELDERBERG (7).

I. NORTH AMERICAN.

1. NIAGARA PERIOD (5).

Epochs. — 1. MEDINA epoch, or that of the Oneida conglomerate and Medina sandstone (5 *a*). 2. CLINTON epoch, or that of the Clinton group (5 *b*). 3. NIAGARA epoch, or that of the Niagara shale and limestone (5 *c*).

I. Rocks: kinds and distribution.

The rocks of the Medina epoch in New York are mainly sandstones and conglomerates; and much of the sandstone is argillaceous. It is not known west of the State of New York, except in Upper Canada and northern Michigan. The lower member is a pebbly sandstone or grit, called the *Oneida conglomerate*, being so named from its occurrence in Oneida County, N. Y. The upper is called distinctively the *Medina sandstone*, and is usually a red or mottled argillaceous sandstone. Both are thin to the north, the former 100 to 120 feet in Oneida County, and the latter 300 to 400 feet along the Niagara River. The conglomerate is 500 feet thick in the Shawangunk Mountains, where it is called the *Shawangunk grit*, and 700 feet in some parts of Pennsylvania and Tennessee. The Medina beds are 1,800 feet thick in Pennsylvania and 500 feet in Tennessee.

In the Eastern-border region, at Anticosti, several hundred feet of limestone represent this epoch.

The rocks of the Clinton and Niagara epochs have a much wider range; and both formations thin out toward the Hudson River. The Clinton beds occur near Canajoharie, in New York, and stretch on west through Canada to Michigan, and along the north side of Lake Huron; and also appear in Ohio, Indiana, and Wisconsin; also south, in Pennsylvania, Virginia, and Tennessee. The rocks in New York and along the northern border of the United States are shaly sandstones, shales, and limestone.

In the formation, there are one or more thin beds of red argillaceous iron ore, made up mostly of small flattened grains; these outcrop in

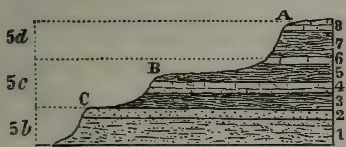
central and western New York, Ohio, and Wisconsin; also along the Appalachians, from Pennsylvania to Alabama; also in Nova Scotia.

The rocks of the Niagara epoch are among the most extensive of the continent, occurring over a large part of the Continental Interior, from New York westward and southwestward; in the Eastern Border region, on Anticosti; and in the Arctic and other parts of British America. In all these regions, they are partly or wholly limestone, the Niagara having been, like the Trenton, one of the *limestone-making* epochs of North America. Near Niagara Falls, there are 165 feet of limestone resting on 80 of shale; and directly at the fall, 85 of limestone over the 80 of shale; and the removal of the shale by the waters is the occasion of the slow retrocession of the falls. Along the Appalachians, the rocks have a thickness of 1,500 feet, and extend to Alabama.

In Illinois and Missouri, there are no shales or sandstones intervening between the limestones of the Cincinnati and Niagara eras; and, as the two formations are continuous, it may be that the Medina and Clinton epochs are there represented by limestone.

1. *Medina Epoch* (5 *a*).

Fig. 396.



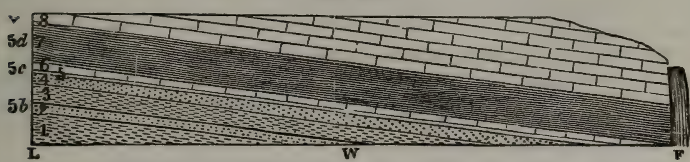
Section at Genesee Falls.

The relation of the Medina group to the overlying Clinton and Niagara groups is well illustrated in one or two sections from the western part of the State of New York. Fig. 396 represents the rocks at Genesee Falls, near Rochester. The lower strata, 1, 2, are the Medina sandstone (5 *b*); 3, 4, 5, 6, the Clinton group (5 *c*); and 7, 8, the Niagara group (5 *d*), — 2 being a grit rock, 3 and 5 shales, 4 and 6 limestone, 7 shale, and 8 limestone. The whole height is about 400 feet.

The following figure (397) represents a section of the rocks along Niagara River, from the bluff at Lewiston (L) to the Falls at F, passing by the Whirlpool at W, — a distance of seven miles.

In the beds at Lewiston, there are *eight* strata: 1, 2, 3, 4 belong to the Medina group, and consist — 1 and 3, of shaly sandstone; 2 and 4, of hard sandstone; 5, of shale, and

Fig. 397.



Section along the Niagara, from the Falls to Lewiston Heights.

6, limestone, are of the Clinton group; 7, a shale, and 8, limestone, of the Niagara group. The dip is up-stream, as in the figure, but is only fifteen feet to a mile.

Where fullest developed in New York, the Medina group includes four divisions, as follow: —

4. Red marl or shale, and shaly sandstone, resembling No. 2, below; banded, and spotted with red and green.

3. Flagstone, — a gray, laminated quartzose sandstone, called "gray band."

2. Argillaceous sandstone and shale, red, or mottled with red and gray.

1. Argillaceous sandstone, graduating below into the Oneida conglomerate.

In the Genesee section (Fig. 397), the strata 1 and 2 correspond to 2 and 3 of these divisions; and the Niagara section contains 2, 3, and 4.

The Oneida Conglomerate is the surface rock in Oneida and Oswego counties, N. Y. It is here 20 to 120 feet thick, but thins out to the eastward, in Herkimer County. The Esopus millstones are made of it.

In East Tennessee, the rock is a hard, whitish, thick-bedded sandstone, 400 feet thick, partly a conglomerate, and in many places filled with *Scolithus* (fillings of worm-borings).

The Medina beds spread through western New York west of Utica. In East Tennessee, in White Oak Mountain, they are 400 to 500 feet thick. In Canada, they occur, south of the St. Lawrence, over a few areas east and northeast of Lake St. Peter.

In Ohio, a few feet of shales, at the top of the Cincinnati Group, have the red color and sandy texture of the Medina, though to a less degree than at its typical localities; but no characteristic fossils of that age have yet been found in them. (Orton.) In southern Indiana, similar beds contain Cincinnati group fossils, up to the very line of junction with the Clinton. (Bradley.)

2. *Clinton Epoch.*

The sandstone of the Clinton epoch in New York is often quite hard; and much of it has the surface uneven from knobby and vermiform prominences, some of which are due to Fucoids.

a. Interior Continental basin. — On the Genesee (see Fig. 396, p. 219), the Clinton group consists of, —

(1.) 24 feet of *green shale*, of which the lower part is shaly sandstone and the upper part an *iron-ore* bed; (2.) 14 feet of limestone, called *Pentamerus limestone*, from a characteristic fossil; (3.) 24 feet of *green shale;* (4.) 18½ feet of limestone, called the *upper limestone.*

On the Niagara (see section, Fig. 397, p. 219), there is only a shale 4 feet thick, *without* the iron-ore, overlaid by a limestone stratum 25 feet thick, — this limestone corresponding to the three upper divisions, and its upper 20 feet to the upper limestone. To the eastward, in Oneida, Herkimer, and Montgomery counties, the rock is 100 to 200 feet thick, and includes no limestone, though partly calcareous. The group consists of shale and hard grit or sandstone, in two or more alternations, along with two beds of the lenticular iron-ore. The flattened grains making up this ore are concretions like those of an oölite. Near Canajoharie — which is not far from its eastern limit — the formation has a thickness of 50 feet. In the town of Starkville, Herkimer County, the rock contains a good bed of gypsum. In the southern part of Herkimer County, the beds are separated from the Hudson River shales by only a small thickness of the Oneida conglomerate.

In Ohio and Southern Indiana, the Clinton group, 10 to 60 feet thick, is recognized by its fossils, overlying the shaly limestone of Cincinnati. In Wisconsin, there is a bed of lenticular iron-ore, 6 to 10 or even 15 feet thick, which is referred to the Clinton epoch.

North of Lake Huron, the Clinton beds occur along the Manitoulin Islands, Drummond Island, and 20 miles to the westward.

b. Appalachian region. — In Pennsylvania, Professor H. D. Rogers divides the rocks into (1) a lower slate, which at Bald Eagle Mountain is 700 feet thick; (2) iron-sandstone, 80 feet in the Kittatinny Mountain; (3) upper slate, 100 to 250 feet; (4) lower shale, 100 to 250 feet; (5) ore-sandstone, 25 to 110 feet; excepting the last, these strata

augment in thickness to the northwest; (6) upper shale, 120 to 250 feet, which thickens to the northwest; and (7) red shale or marl, 975 feet thick, at the Lehigh Water-Gap. The formation spreads across the State, "from the northwest flank of the Kittatinny Mountain to the similar slope of the last main ridge of the foot of the Alleghany Mountains." (H. D. Rogers.) In East Tennessee, the rocks are 200 to 300 feet thick, and include one or two beds of argillaceous lenticular iron ore.

c. Eastern-border region. — The relations of the limestones of Anticosti to this epoch have been mentioned on p. 206.

In Nova Scotia, at Arisaig, where the rocks are shales and limestone, and have a thickness of about 500 feet, fossils occur throughout the formation, and are very abundant in the upper or more calcareous part. These rocks may be partly Lower Helderberg, according to Dawson. At the East River of Pictou, there are also slates and calcareous bands, probably of the same age. They include a deposit of oölitic iron-ore, like that of the Clinton rocks of central New York, which in some places has a thickness of 40 feet. Shales and sandstone occur also in New Brunswick, northeast and southeast of Passamaquoddy Bay.

3. *Niagara Epoch.*

a. Interior Continental basin. — At Rochester, N. Y., there are about 80 feet of limestone, overlying 80 of shale. Farther eastward, in Wayne County, the limestone is 30 or 40 feet thick, and in Cayuga County still less. The formation appears to thin out in Herkimer County. It is, however, represented in the Helderberg Mountains, south and west of Albany, by a bed of limestone about 25 feet thick, called the *Coralline limestone.* From New York, the formation extends westward into Canada, and then northward around the north side of Lake Huron, the north and west sides of Lake Michigan, and thence westward through northern Illinois into Iowa. In Ohio, it outcrops, like the Clinton, around the area of Cincinnati limestone. Throughout these regions, the rock is almost wholly limestone. In the peninsula of Michigan, the thickness is about 100 feet; in Ohio, the lower part of the Cliff limestone, 300 feet.

In West Tennessee, the Meniscus limestone, 150 to 200 feet thick, noted for its fossil sponges, of which one is meniscus-shaped, is probably the equivalent of the Niagara limestone.

The Galt or Guelph limestone, well seen at Galt and Guelph in Western Canada, and farther west, which was formerly supposed to be of the age of the Salina beds, is now regarded as the upper part of the Niagara limestone. The Leclaire limestone of Iowa has the same position.

b. Appalachian region. — In Pennsylvania, the formation consists of two distinct deposits of marl or fragile shale. The lower is about 450 feet thick, where most developed, near the middle belt of the Appalachian zone, and decreases both to the southeast and northwest. The upper deposit, including some thin limestone layers, is 1,200 feet thick in the northwest belt, and declines to the southwest (H. D. Rogers). These strata may include, besides the true Niagara, strata of the Salina or Salt-group period.

c. Eastern-border region. — The Niagara limestone is supposed to occur in eastern Canada, some distance south of the St. Lawrence. It is part, according to Logan, of an extensive formation, which stretches from northern Vermont, *eastward* over a part of northern New Hampshire and northern Maine, to Cape Gaspé on St. Lawrence Bay, being, in this part, limestone with some massive and shaly sandstone. The formation embraces also the strata of the Lower Helderberg, and possibly part of those of the Lower Devonian. Niagara fossils occur near Lake Memphremagog and in the lower part of the Gaspé limestone, as well as at some intermediate points.

Near New Canaan, in Nova Scotia, there are clay slates of the Niagara epoch.

d. Arctic regions. — In the Arctic, the Niagara limestone has been observed between the parallels of 72° and 76°, on the shores of Wellington and Barrow Straits, and on King William's Island. The common Chain-coral *Halysites* (*Catenipora*) *catenulata*

has been found at several localities, along with other Upper Silurian species. (See, further, p. 230.)

The color of the Niagara limestone is commonly dark bluish-gray to drab. It is sometimes quite impure, and good for hydraulic purposes. A specimen from Makoqueta, Jackson County, Iowa, afforded J. D. Whitney — Carbonate of lime 52·18, carbonate of magnesia 42·64, — with 0·35 of carbonate of soda, *traces* of potash, carbonate of iron, chlorine, and sulphuric acid, 0·63 of alumina and sesquioxyd of iron, and 4.00 insoluble in acid, — making it nearly a true dolomite.

Structural peculiarities. — The Medina beds bear evidence of having been formed as a sand-flat or reef accumulation. Besides the thin lamination alluded to, they abound in ripple-marked slabs (Fig. 62, p. 83); mud-cracks (Figs. 64, 65), due to sun-drying; wave-lines; rill-marks about stones and shells (Fig. 63); and diagonal lamination (Fig. 61 *e*), an effect of tidal currents. Fig. 63 is drawn from a slab of Medina sandstone. All these peculiarities evince that the accumulations, while forming, were partly in the face of the waves and currents, and partly exposed above the waves to the drying air or sun, and to the rills running down a beach on the retreat of the tides or waves.

The structure of the Niagara limestone is often nodular or concretionary. In Iowa and some other parts of the West, the rock abounds in chert or hornstone, which is usually in layers coincident with the bedding, like flint in chalk; and the fossils are all siliceous. At Lockport, N. Y., cavities in the limestone afford fine crystallizations of dog-tooth spar (calcite) and pearl-spar (dolomite), with gypsum, and occasionally celestite, and still more rarely a crystal of fluor.

The Niagara limestone (like many others) sometimes breaks vertically with smooth columnar surfaces; and such specimens have been called *Stylolites.* Prof. O. C. Marsh has shown that the columns are often capped by a shell; and that this shell has, in some way, kept the material beneath from the compression which the parts around underwent, and hence the vertical surfaces. The shell probably acted by causing an earlier hardening of the material it covered.

Economical products. — The Ulster lead and copper mine, near Redbridge, N. Y., is situated in the Shawangunk Grit: it has afforded large masses of galena and copper pyrites, with blende, but is not worked. The Ellenville and Shawangunk mines are others of similar character in the grit.

Mineral oil occurs in large quantities in the Niagara limestone at Chicago, though not capable of being collected to advantage. Worthen says, that a portion of the limestone is "completely saturated with oil."

II. Life.

The rocks of the Medina epoch in New York, and farther west, contain few fossils, while those of the Clinton abound in them. The Anticosti beds of the same era show that there was a profusion of life in the seas, through both epochs. The Niagara beds are generally full of fossils.

1. *Plants.*

The only fossil plants are Algæ (sea-weeds), called *Fucoids.* Forms referred to this group are common in the sandstones of the Medina and Clinton beds, but rare in the limestones of the Niagara period (limestones seldom containing fossil sea-weeds). Fig. 398 represents portions of a fossil supposed to be the cast of a sea-weed. It has been suspected to be the cast of the tracks of large worms. It covers thickly some layers of the Medina sandstone. Other fucoids of these rocks are rounded branching stems, from the size of a thread to that of a finger.

2. *Animals.*

The sandstones and shales of the Medina and Clinton groups contain, besides great numbers of Brachiopods, many Lamellibranchs, with few Corals or Crinoids; while the limestones of the Clinton

Figs. 398–403.

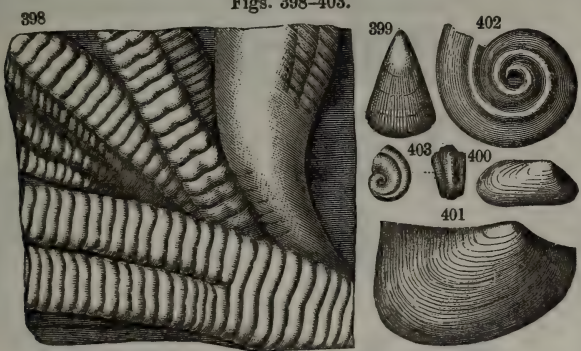


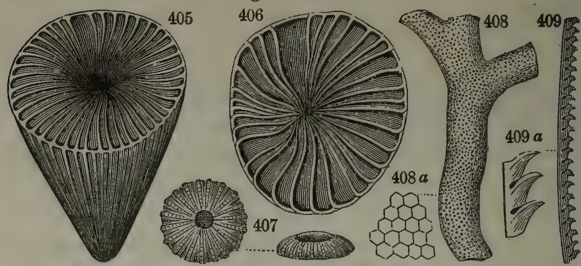
Fig 398, Arthrophycus Harlani; 399, Lingulella cuneata; 400, Modiolopsis orthonota; 401, M. (?) primigenia; 402, Pleurotomaria litorea; 403, Bucanella trilobata.

group, and especially those of the Niagara, abound in Brachiopods, Corals, Crinoids, and Trilobites, and contain few Lamellibranchs or muddy-bottom species. Some of the limestone beds were originally coral reefs. No evidences of fishes or freshwater life have been observed. One of the most common *Medina* species is a wedge-

shaped *Lingulella, L. cuneata* (Fig. 399). Two of the Lamellibranchs of the same beds are represented in Figs. 400, 401, and two Gasteropods in Figs. 402, 403. A considerable number of the Medina species are identical with the Clinton.

The following figures represent fossils of the *Clinton* group, —

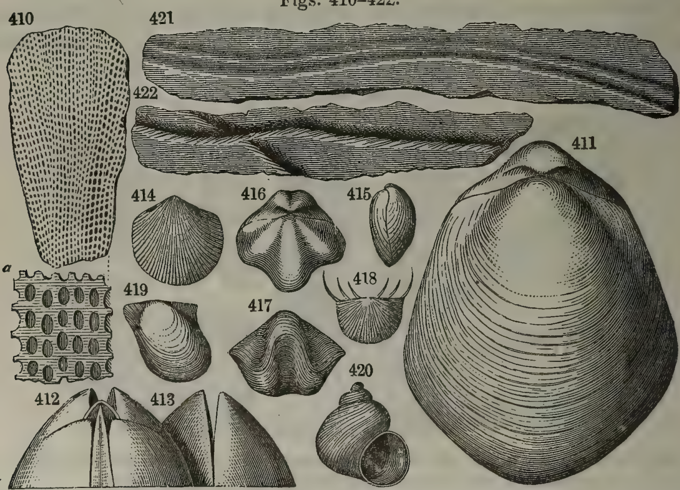
Figs. 405–409.



Radiates. — Figs. 405, 406, Zaphrentis bilateralis; 407, 407, Palæocyclus rotuloides; 408, *a*, Chætetes; 409, *a*, Graptolithus Clintonensis.

Figs. 405, 406, one of the common corals, a cup coral or Cyathophylloid, of the genus *Zaphrentis;* 407, a small Echinoid; 408, a fine

Figs. 410–422.



Mollusks. — Figs. 410, *a*, Fenestella (?) prisca; 411, Pentamerus oblongus; 412, 413, part of casts of the interior; 414, 415, Atrypa reticularis; 416, 417, Athyris (formerly Atrypa) congesta; 418, Chonetes cornuta; 419, Avicula rhomboidea; 420, Cyclonema cancellatum; 421, track of a Lamellibranch (×½); 422, track of an Annelid? (×½).

columnar coral, of the genus *Chætetes;* 409, a Graptolite; 410, a delicate reticulated Bryozoan coral; 411 to 418, some of the Brachio-

pods, of which 411, *Pentamerus oblongus,* is a large and characteristic species, occurring also in the Niagara beds of Illinois, Wisconsin, and

Fig. 422 A.

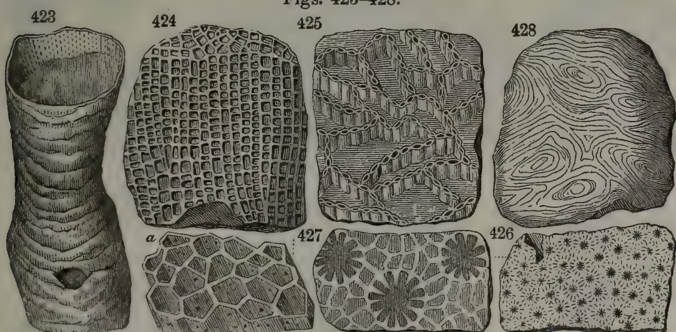
Cruziana ? (Rusophycus) bilobatus.

Iowa; 419, a Lamellibranch, of the genus *Avicula;* 420, a Gasteropod, of the genus *Cyclonema.* Fig. 421 represents a trail, supposed to be that of a Mollusk; and 422, that of a worm (Annelid).

Fig. 422 A represents a cast common in the Clinton sandrock. It was formerly supposed to be a sea-weed, but is now regarded as the cast of the trail of an Articulate.

In the *Niagara* group, among the many corals, there are the following, here represented. Fig. 423 is one of the Cyathophylloids or cup corals; 424, one of the *Favosites,* a columnar coral so named from

Figs. 423–428.



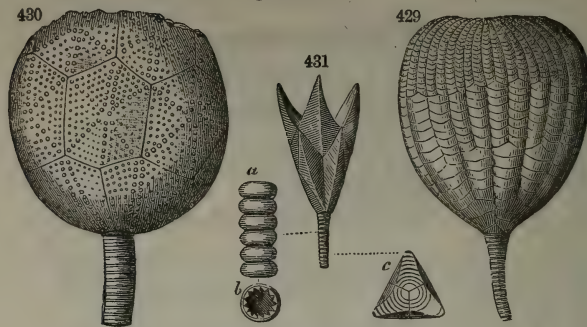
CORALS. — Fig. 423, Chonophyllum Niagarense; 424, *a*, Favosites Niagarensis; 425, Halysites catenulata; 426, 427, Heliolites spinipora; 428, Stromatopora concentrica.

favus, a honeycomb, in allusion to its columnar structure (shown in Fig. 424 *a*); 425, a *chain* coral, or species of *Halysites,* 428 a *Stromatopora,* probably a Protozoan coral, either a calcareous Sponge or a Foraminifer.

Three of the Niagara Crinoids are illustrated in Figs. 429–431; 429 shows the cluster of arms at top, which in the living state opened

out, flower-like; 430 shows the box-like body above, but wants the arms.

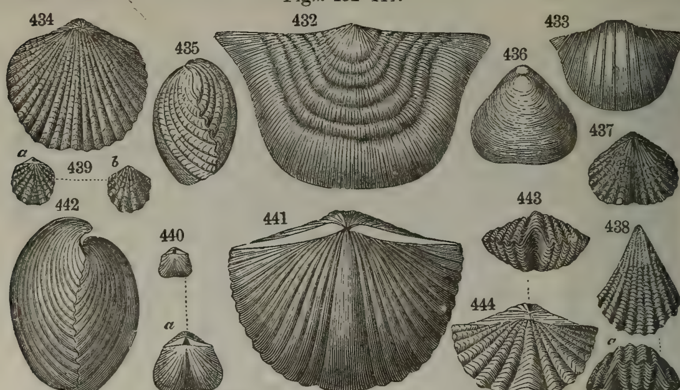
Figs. 429–431.



Crinoids. — Fig. 429, Ichthyocrinus lævis; 430, Caryocrinus ornatus; 431, *a*, *b*, *c*, Stephanocrinus angulatus.

Some of the characteristic Brachiòpods are represented, natural size, in Figs. 432 to 444 — all very abundant species in the Niagara limestone. The shell of a large Lamellibranch, from the upper part

Figs. 432–444.

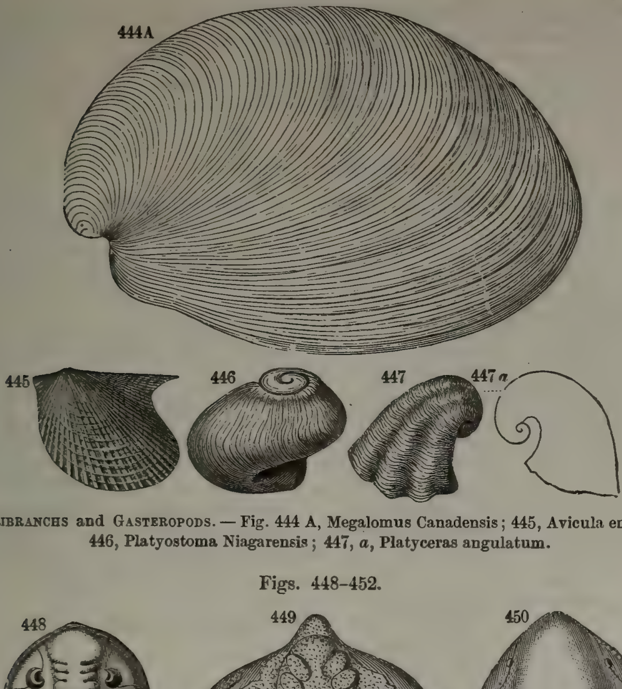


Brachiopods. — Fig. 432, Strophomena rhomboidalis; 433, Leptæna transversalis; 434, 435, Atrypa nodostriata; 436, Merista nitida; 437, Anastrophia interplicata; 438, *a*, Rhynchonella cuneata; 439, *a*, *b*, Leptocœlia disparilis; 440, *a*, Orthis bilobus; 441, 442, Spirifer Niagarensis; 443, 444, Sp. sulcatus.

of the Niagara group, is represented in Fig. 444 A. Another more common kind, of the genus *Avicula*, is shown in Fig. 445, reduced one half in breadth; and Figs. 446, 447 represent two Niagara Gasteropods.

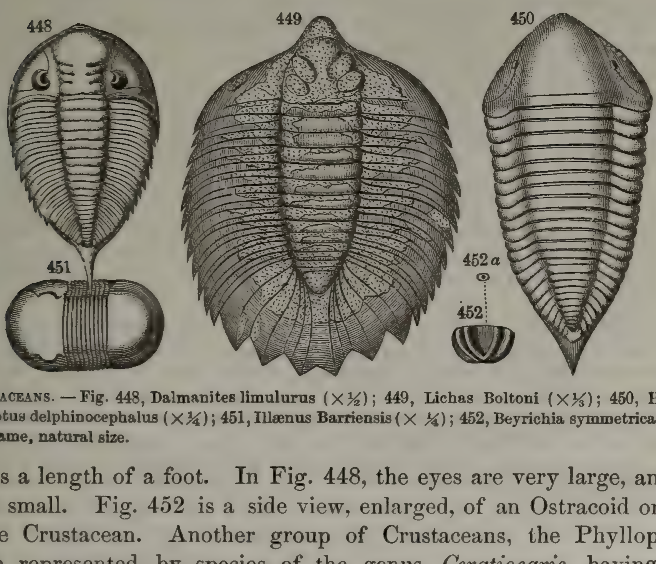
Figs. 448 to 451 represent some of the Niagara Trilobites; 449 is one third the actual length, and 450 a fourth, the latter attaining some-

Figs. 444 A–447.



Lamellibranchs and Gasteropods. — Fig. 444 A, Megalomus Canadensis; 445, Avicula emacerata; 446, Platyostoma Niagarensis; 447, *a*, Platyceras angulatum.

Figs. 448–452.



Crustaceans. — Fig. 448, Dalmanites limulurus (×½); 449, Lichas Boltoni (×⅓); 450, Homalonotus delphinocephalus (×¼); 451, Illænus Barriensis (× ¼); 452, Beyrichia symmetrica; 452, *a*, same, natural size.

times a length of a foot. In Fig. 448, the eyes are very large, and in 450, small. Fig. 452 is a side view, enlarged, of an Ostracoid or bivalve Crustacean. Another group of Crustaceans, the Phyllopods, were represented by species of the genus *Ceratiocaris*, having, as shown in Fig. 484, on page 247, the general form of a Shrimp.

Characteristic Species.

1. Medina Epoch.

Fig. 398, *Arthrophycus Harlani* H. Occurs rarely in the Oneida conglomerate, very abundantly in the Medina beds. Fig. 399, *Lingulella cuneata* H. ; 400, *Modiolopsis orthonota* H.; 401, *M.* (?) *primigenia* H.; 402, *Pleurotomaria litorea* H.; 403, *Bucanella trilobata* Sow., different views. *Orthocerata* are ocasionally met with. The only Crustacean described is the Ostracoid, *Leperditia cylindrica* Hising.

2. Clinton Epoch.

1. Radiates. — (*a.*) *Polyps.* — Figs. 405, 406, *Zaphrentis* (*Caninia*) *bilateralis* H.; 408 a branching *Chætetes.* (*b.*) *Acalephs.* — 409, *a*, *Graptolithus Clintonensis* H. (*c.*) *Echinoderms: Crinoids.* — A few species are known: fragments are common, and they are often found in the iron-ore, as well as in the limestones. *Echinoids.* — Fig. 407, *Palæocyclus rotuloides* H., a small species.

2. Mollusks. — (*a.*) *Bryozoans.* — Fig. 410, *Fenestella* (?) *prisca* Lonsdale.

(*b.*) *Brachiopods.* — There are species of *Lingulella, Orthis, Leptæna, Rhynchonella, Spirifer*, and also of the new genera for America, *Chonetes* and *Pentamerus.* Fig. 411, *Pentamerus oblongus* Murch.; some specimens are more than twice the size of this figure, and very thick; it is abundant in New York and the West, and occurs also in Great Britain; Figs. 412, 413 show casts of the interior, — 412 a dorsal view, and 413 a ventral. Figs. 414, 415, *Atrypa reticularis* Linn., or a related species; the *A. reticularis* is reputed to extend through the Niagara period into the Hamilton of the Devonian; but more than one species are probably here included; this also is a foreign species: it is one of the few species of true *Atrypa*; the interior of the shell is shown in Fig. 225. Fig. 416, *Athyris* (?) *congesta* Con.; Fig. 417, same, different view, — it has a spire within, extending downward and outward; Fig. 418, *Chonetes cornuta* Koninck.

(*c.*) *Lamellibranchs.* — Fig. 419, *Avicula rhomboidea* H.

(*d.*) *Gasteropods.* — Fig. 420, *Cyclonema cancellatum* H. *Bucanella trilobata* of the Medina also occurs here, besides other Gasteropods.

(*e.*) *Cephalopods.* — Species of *Orthoceras.*

In the Anticosti beds, there are Cephalopods of the genera *Orthoceras, Cyrtoceras, Oncoceras, Ascoceras, Glossoceras*, as well as *Beatricea*; and Trilobites of the genera *Asaphus, Calymene, Illænus, Phacops, Dalmanites, Encrinurus, Harpes, Lichas*, etc., and among these, *Asaphus megistos* and *Calymene Blumenbachii.* If the so-called *Beatriceæ* were the internal bones of Cephalopods, as seems probable (after Hyatt's observations), some of these animals must have been 20 or 30 feet long. The fossils are somewhat like a long straight branch of a tree, with an irregularly fluted or otherwise uneven exterior, and have been described as remains of plants; but they have a cone-in-cone structure, with cellular interspaces about the center, and the plates in contact toward the sides. They are from 1 to 14 inches in diameter.

3. Articulates. — Remains of Trilobites of the genus *Homalonotus*, and of the same species figured under the Niagara epoch. Tracks or scratches occur, which have been referred with good reason to Crustaceans, besides others like Fig. 422, that are attributed to Worms.

Among the Clinton species are the following from the Lower Silurian: *Orthis lynx, Leptæna sericea, Bellerophon bilobatus.* The following are known in Europe: *Orthis lynx, Chonetes cornuta* H., *Atrypa reticularis, A. hemispherica* Murch., *Spirifer radiatus* Sow., *Pentamerus oblongus.*

3. Niagara Epoch.

1. Protozoans. — Sponges of the genera *Astræospongia, Astylospongia* and *Palæomanon* in Tennessee; they occur in the upper part of the Niagara (or Meniscus) lime-

stone. Roemer made out six species, of which *Astræospongia meniscus* is the most abundant. Fig. 428, *Stromatopora concentrica* H., a very minutely porous coral, often in concentric layers.

2. Radiates. — (*a.*) *Polyps* (Corals). — Fig. 423, *Chonophyllum Niagarense* H., (*Conophyllum* of Hall, a genus first published in 1852, two years after *Chonophyllum* by Edwards); 424, *Favosites Niagarensis* H.; 424 *a*, surface of same, enlarged, showing outline of cells; 425, *Halysites catenulata;* 426, *Heliolites spinipora* H.; 427, an enlarged view, showing the 12-rayed cells and the interval of a cellular character separating them, both of which are distinguishing characteristics of the genus *Heliolites.*

(*b.*) *Echinoderms.* — Fig. 429, *Icthyocrinus lævis* Conrad, a species which is sometimes wice as large as the figure; 430, *Caryocrinus ornatus* Say, of Lockport, the nut-like shape having suggested the generic name (from *Carya*, the hickory-nut); 431, *Stephanocrinus angulatus* Conrad, of Lockport; *a*, part of the stem, enlarged; *b*, joint of the stem, top-view; *c*, base of the body, showing the three pieces of which it consists. Also, Fig. 146 (page 117), the Cystid *Callocystites Jewettii* H., and Fig. 144, the Starfish *Palæaster Niagarensis* H.

3. Mollusks. — (*a.*) *Bryozoans.* — Many species of delicate corals of the genus *Fenestella*, resembling Fig. 410, and of other genera. (*b.*) *Brachiopods.* — Fig. 432, *Strophomena rhomboidalis* Wahl.; 433, *Leptæna transversalis* Dalman; 434, *Atrypa nodostriata* H., the Niagara form of this species; 435, same, side-view; 436, *Merista nitida* H., 437, *Anastrophia* (or *Brachymerus*) *interplicata* H.; 438, *a*, *Rhynchonella cuneata* H.; 439, *a*, *b*, *Leptocœlia disparilis* H.; 440, *Orthis bilobus* H.; 440 *a*, same, enlarged; 441, *Spirifer Niagarensis* Con.; 442, same, side-view; 443, 444, *Sp. sulcatus* Hising. *Pentamerus oblongus* (Fig. 411), a Clinton group species, is very abundant in the Niagara limestone of the Mississippi basin. Among these, all but the *Leptocœlia isparilis* H , *Atrypa nodostriata* H. and the *Orthis* and *Spirifers*, are found also in European rocks.

(*c.*) *Lamellibranchs.* — Fig. 444 A, *Megalomus Canadensis* H., from the Galt, Canada; 445, *Avicula emacerata* Con.

(*d.*) *Gasteropods.* — Fig. 446, *Platyostoma Niagarensis* H.; 447, *Platyceras angulatum* H.; *a*, same in different position.

(*e.*) *Pteropods.* — *Conulariæ* of different species.

(*f.*) *Cephalopods.* — Species of *Orthoceras*, *Cyrtoceras*, *Gomphoceras*, and *Lituites*, which are common in the Interior basin.

4. Articulates. — (*a.*) *Trilobites.* — Fig. 448, *Dalmanites limulurus* H. (a genus differing from Calymene in having the glabella, or middle region of the buckler, largest anteriorly, besides having large reniform eyes and other peculiarities); 449, *Lichas Boltoni* H., a large and characteristic species, much reduced; 450, *Homalonotus delphinocephalus* Murch. (the genus having very small eyes, the glabella faintly outlined and undivided, — the middle lobe of the body much broader than the lateral); 451, *Illænus Barriensis* Burmeister; *Calymene Blumenbachii* var. *Niagarensis* H., near Fig. 361 (page 202). (*b.*) *Ostracoids*, or bivalve Crustaceans. — Fig. 452, *Beyrichia symmetrica* H., showing one of the valves; *a*, same, natural size. (*c.*) *Phyllopods.* — *Ceratiocaris Deweyi* Hall. The only specimens found in the Niagara beds are the spine-like terminal joint of the body (formerly supposed to belong to a fish, and named *Onchus Deweyi*).

The following are some of the species common to the Niagara and Clinton groups: —

Halysites catenulata (Fig. 425).	Spirifer radiatus.
Caryocrinus ornatus (Fig. 430).	Avicula emacerata (Fig. 445).
Hypanthocrinus decorus.	Orthonota curta?
Lingula lamellata.	Modiolopsis subalata?
Orthis elegantula (Fig. 389).	Ceraurus insignis.
Strophomena rhomboidalis (Fig. 432).	Homalonotus delphinocephalus (Fig 450).
Pentamerus oblongus (Fig. 411).	Calymene Blumenbachii.
Rhynchonella neglecta.	Dalmanites limulurus (Fig. 448).
Atrypa reticularis (Fig. 414).	Illænus Barriensis (Fig. 451).

According to Salter, a number of species of the Upper Silurian, and probably of this part of it, have been observed in Arctic rocks; as, *Halysites catenulata*, *Orthis elegantula*, *Favosites Gothlandica*, *Leperditia Baltica* Hising., species of *Calophyllum*, *Heliolites*, *Cystiphyllum*, *Cyathophyllum*, *Syringopora*, with *Pentamerus conchidium* Dalm., *Atrypa reticularis*, etc.; and, at the southern extremity of Hudson's Bay, *Pentamerus oblongus*, *Atrypa reticularis*, etc. About Lake Winnipeg, also, Upper Silurian fossils have been found. See Am. Jour. Sci., II. xxi. 313, xxvi. 119.

The fossils of the Coralline limestone (p. 222), as Hall states, are mostly peculiar to it. Out of thirty-two species (including Corals, Brachiopods, Conchifers, Gasteropods, Cephalopods, and Crustaceans) only the following are set down as identical with Niagara fossils: *Stromatopora concentrica*, *Favosites Niagarensis*, *Halysites catenulata*, *Spirifer crispus*, *Rhynchonella lamellata* H.; and these are not all beyond doubt. Moreover, three of them are cosmopolite species. The beds are, therefore, strikingly different in life from the Niagara, and may represent a later epoch. Among the species, there are very large spiral chambered shells, of the genus *Trochoceras* Hall, which are unknown in other formations.

General Observations on the Niagara Period.

Geography. — The facts upon which rest the conclusions with regard to the geography of the Niagara period are, —

1st. The occurrence of the Oneida conglomerate over the region from central New York southward, through the length of the Appalachians, instead of extending eastward to the Hudson River.

2d. The Medina sandstone covering the same region, but spreading farther westward on the north.

3d. The Clinton group having the same range on the east, and extending over a considerable part of the interior basin to the Mississippi; shales characterizing the formation in the Appalachian region, shales and sandstones prevailing over limestones in New York, and limestones, more or less argillaceous, mostly constituting the beds in the West.

4th. The Niagara rocks, stretching farther east, but thinning out on the Hudson River, and thickening westward; spreading over the Appalachian region, and also through a large part of the Interior basin; consisting of shales with some limestone in central New York, more limestone in the western part of the State, shales almost solely in the Appalachian region, limestones in the Interior basin.

5th. The formations six to eight times thicker in the Appalachian region than in the West.

6th. The Niagara limestone existing in the Eastern-Border region, eastward of northern Vermont, to Gaspé; and the whole period represented in Anticosti by limestone.

The position of the coarse conglomerate rocks of the Oneida epoch, spreading over neither eastern New York nor the Interior basin west of the State, apparently indicates that along its line was the sea-coast of the time, and that the ocean reached it in full force. Such coarse beds of marine formation are formed either in front of the waves, or

under the action of strong marine currents. The making of the Green Mountains must have placed the region more or less above the sea-level; for the absence of the earlier formations of the Niagara period from eastern New York, and the thinning eastward of the Niagara beds, harmonize with this view.

The fine sandy and clayey character of the Medina beds shows that at this time central New York must have become an extensive area of low, sandy sea-shores, flats, and marshes, not feeling the heavy waves; and this kind of surface extended westward over Michigan, instead of having a limit in central New York. There is abundant evidence, in the ripple-marks, wave-marks, rill-marks, and sun-cracks, of the existence of shallow waters and emerging sand-flats.

The clays, clayey sandstones, and limestones of the Clinton epoch, through New York and the Appalachians, show that the mud-flats and sand-banks, and hence the shallow seas of the coast region, still continued, yet with some greater depth of water at times, in which impure limestones could be formed; and the many alternations of these limestones with shales and sandstones imply frequent changes of depth over these areas, as remarked by Hall. At the same time, the westward extension of the formation, and the prevalence of limestones, indicate that the waters covered a considerable part of the Interior Continental basin; while the impurity of the rock suggests that these inner seas were in general quite shallow. The beds of argillaceous iron-ore, which spread so widely through New York and some of the other States west and south, could not have been formed in an open sea; for clayey iron-deposits do not accumulate under such circumstances. They are proof of extensive marshes, and, therefore, of land near the sea-level. The fragments of Crinoids and shells found in these beds are evidence that they were, in part at least, salt-water marshes, and that the tides sometimes reached them.

The beds of the Niagara epoch on the east indicate that the waters shallowed toward the Hudson River; at the same time, the thick limestones of western New York and the Mississippi basin teach that there was then a great open interior sea, nearly as in the Trenton period, though more beautiful, since Corals and Crinoids were a more prominent feature of the era.

If the above is a correct view of the geographical changes, it is seen that, after the Medio-Silurian revolution, which raised the Green Mountain region, even eastern New York was, in the first two epochs of the Niagara period, above water; but there was then a gradual sinking of the land, which moved the coast-line in New York eastward to the Hudson, so that, over New York and the Interior basin, there was a vast limestone-making sea. We infer that this oscillation of

level was slow, from the fact that the change in the coast-line in New York, from central New York to the Hudson, demanded the whole of the Medina and Clinton epochs. This change, moreover, was the beginning of a submergence of the east as well as the west side of the Hudson River valley, which continued through the Lower Helderberg period.

At the same time that the sea of the Niagara epoch spread over New York and the Interior basin, there was another sea of no small area, over the Eastern Border region, covering the Gulf of St. Lawrence and part of the country south of the St. Lawrence region,— the exact extent not yet ascertained. In the course of these oscillations, from the beginning of the Trenton to the close of the Niagara period, over 12,000 feet of rock were deposited along the Appalachians, indicating a vast subsidence, in slow progress as the accumulations went on. Without the subsidence, great breadth of deposits might have been formed, but not great thickness. The whole change of level over the Interior Continental basin may not have exceeded 1,000 feet.

With regard to the continent beyond the Mississippi, we have small basis for conclusions. About the Black Hills and the east side of the Laramie Range, the Carboniferous strata are stated by Hayden to rest on those of the Lower Silurian, and, therefore, there is an absence of all the formations of the Upper Silurian and Devonian; but on the east side of the Wind River range Comstock has found some Niagara and Oriskany species. About the El Paso Mountains in New Mexico, between the rivers Pecos and Grande (near lat. 32°), Dr. G. G. Shumard found a limestone of the Trenton or Cincinnati era, containing the fossils *Orthis testudinaria*, *O. occidentalis* H., *Rhynchonella capax* Conrad, and others; but to this succeeded the Carboniferous. More investigation is needed to establish the general fact; but if true, as supposed, a part of the region beyond the Mississippi was in no condition for the formation of limestones or sandstones, between the Lower Silurian and the Carboniferous, either because at too great a depth, or because emerged.

The Niagara period was, in part at least, one of continental submergence also in Arctic America and Europe. Even Great Britain had its Coral and Crinoidal seas, and thereby its limestone formations in progress,—although the Silurian there contains comparatively little limestone, owing to the fact that the country lies, like the Appalachian region, within the mountain-border of a continent.

2. SALINA PERIOD (6).

The *Salina* is the period of the Onondaga Salt-group, the series of rocks that affords the salt from brines in Central New York.

I. Rocks: kinds and distribution.

The Niagara period had covered the sea-bottom in western New York with an extensive formation of limestone. With the opening of the Salina period, there was a change by which shales or marlytes

and marly sandstones, with some impure limestones, were formed over a portion of the State; and in some way the strata were left impregnated with salt, and also almost destitute of fossils.

The beds spread through New York, and mostly south of the line of the Erie Canal. They are 700 to 1,000 feet thick in Onondaga and Cayuga counties, and only a few feet on the Hudson.

The following sections (Figs. 453, 454, from Hall), taken on a north-and-south line south of Lake Ontario, show the relations of the Salina beds (6) to those above and below, — they being underlaid in one section (Fig. 454) by the Niagara (5 *c*), Clinton (5 *b*), and Medina (5 *a*) beds, and overlaid in the other (Fig. 453) by rocks of the

Fig. 453.

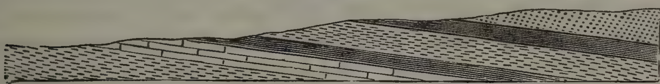


Fig. 454.

Lower and Upper Helderberg (7, 9), Hamilton (10 *a*, 10 *b*, 10 *c*) and Chemung groups (11).

To the westward, they outcrop between Niagara and Lake Huron, and also about Mackinac.

Through the Mississippi basin, the limestone of the Niagara period is followed directly by that of the next or Lower Helderberg period; and the Salina period is not represented, unless by some of the transition beds between these limestone formations.

In Onondaga County, N. Y., the beds in the lower half are (1) tender, clayey deposits (marlytes) and fragile clayey sandstones of red, gray, greenish, yellowish, or mottled colors; and in the upper half (2), calcareous marlytes and impure drab-colored limestone, containing beds of gypsum, overlaid by (3) hydraulic limestone. This limestone afforded Dr. Beck, on analysis — Carbonate of lime 44·0, carbonate of magnesia 41·0, clay 13·5, oxyd of iron 1·25. The rock is sometimes divided by columnar striations, like the Lockport limestone, the origin of which is probably the same as for those in that rock (p. 222). The seams sometimes contain a trace of coal or carbon.

Near Syracuse, there is a bed of serpentine in this formation, along with whitish and black mica, and a granyte-like rock, in which hornblende replaces the mica, making it a syenyte; there is little evidence of heat in the beds adjoining these metamorphic rocks. (Vanuxem.) (The position of this locality is not now known).

In the peninsula of Michigan, the formation includes — beginning below — 10 feet of variegated gypseous marls, 14 feet of ash-colored argillaceous limestone, 3 feet of calcareous clay, and 10 feet of chocolate-colored limestone. (Winchell.) In western Ohio, the beds are 20 to 30 feet thick.

In southwest Virginia, a few feet of marly shales with a heavy bed of gypsum yield the strong brine of the wells at Saltville.

The beds, especially those of the upper half, are much intersected by shrinkage-cracks, — effects of the drying of the mud of the ancient mud-flat by the sun.

Minerals. — The gypsum does not constitute layers in the strata, but lies in imbedded masses, as shown in the annexed figures. The

Fig. 455.

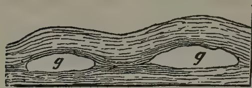


Fig. 456.

lines of stratification sometimes run through it, as in Fig. 456; and in other cases the layers of the shale are bulged up around the nodular masses (Fig. 455). In all such cases, the gypsum was formed after the beds were deposited. Sulphur springs are now common in New York, and especially about Salina and Syracuse. Dr. Beck describes several occurring in this region, and mentions one near Manlius, which is "a natural sulphur-bath, a mile and a half long, half a mile wide, and 168 feet deep, — a fact exhibiting in a most striking manner the extent and power of the agency concerned in the evolution of the gas," and showing, it may be added, that the effects on the rocks below must be on as grand a scale. These sulphur-springs often produce sulphuric acid, by an oxydation of the sulphuretted hydrogen. There is a noted "acid spring" in Byron, Genesee County, N. Y., connected with the Onondaga formation, besides others in the town of Alabama. This sulphuric acid, acting on limestone (*carbonate* of lime), drives off its carbonic acid and makes *sulphate* of lime, or gypsum; and this is the true theory of its formation in New York. The laminæ which pass through the gypsum unaltered, as in Fig. 456, are those which consist of clay instead of limestone. The gypsum is usually an earthy variety, of dull gray, reddish and brownish, sometimes black, colors. It may have been produced at any time since the deposition of the rocks; and it is beyond doubt now forming at some places in the State.

The salt of the rocks in New York has been found only in solution, in waters issuing from the strata. The wells at Salina are 150 to 310 feet deep, and, at Syracuse, between 255 and 340. 35 to 45 gallons of the water afford a bushel of salt; while it takes 350 gallons of sea-water for the same result. At Goderich, in Canada, *Rock salt* has been obtained at a depth of from 964 to 1,180 feet, and is reported to exist in beds from 14 to 40 feet in thickness.

II. Life.

The Salina beds are for the most part destitute of fossils. The lower beds in New York contain a few species, imperfectly preserved; and the same is true of the upper. The latter, however, are regarded as rather of the next (Lower Helderberg) period.

III. General Observations.

Geography. — The position of the Saliferous beds over the State of New York indicates that the region, which in the preceding period was covered with the sea, and alive with Corals, Crinoids, Mollusks, and Trilobites, making the Niagara limestone, had now become an interior shallow basin, or a series of basins, mostly shut off from the ocean, where the salt waters of the sea, which were spread over the area at intervals, — intervals of days, or months, or years, it may be, — evaporated, and deposited their salt over the clayey bottoms. In such inland basins, the earthy accumulations in progress would not consist of sand or pebbles, as on an open sea-coast, but of clay or mud, such as is produced through the gentle movements of confined waters. Moreover, the salt waters would become, under the sun's heat, too densely briny for marine life, and at times too fresh, from rains; and the muddy flat might be often exposed to the drying sun, and so become cracked by shrinkage. The shrinkage-cracks, the clayey nature of the beds, the absence of fossils, and the presence of salt, all accord with this view. Salt cannot be deposited by the waters in an open bay; for evaporation is necessary. The warm climate of the Silurian age and the absence of great rivers were two conditions favorable for such results. At some of the smaller coral islands in the Pacific, the lagoon (or lake) of the interior is so shut off from free communication with the ocean, as to exemplify well the above-mentioned conditions. In the confined lagoon, there are often no fragments of corals or shells along the shores, but, instead, a deep mud of calcareous material, made out of the broken shells and corals by the triturating wavelets, — so deep and adhesive that the waters of the lagoon are somewhat difficult of access. This calcareous mud, if solidified, would become a non-fossiliferous limestone, like a large part of the coral rock; and yet, a few hundred yards off on the sea-coast, there are other limestones forming, that are full of corals and shells. In another small Pacific coral island, called Baker's, there is a bed of gypsum two feet thick, attributable to the evaporation of sea-water, as remarked by the describer, J. D. Hague.[1]

The Saliferous flats of New York spread nearly across the State,

[1] *Am. Jour. Sci.*, II. xxxiv. p. 224. Dana's *Corals and Coral Islands*, pp. 182, 294.

and probably opened on the ocean to the southeast. The existence of such interior evaporating flats implies intermittent incursions of the sea, perhaps only through tidal overflows, but also, probably, such occasional floodings as may take place where coast-barriers or reefs are broken through at times by the waves or currents.

As the Saliferous beds of New York are nearly 1,000 feet thick, just west of the centre of the State, and since there is proof in the shrinkage-cracks and other peculiarities that the layers were successively formed in shallow waters, it follows that there must have been a slow subsidence of the region during the progress of the period, — it may have been of but a few inches or feet in a century.

3. LOWER HELDERBERG PERIOD (7).

I. Rocks: kinds and distribution.

The Lower Helderberg period was marked by the formation of thick limestone strata. There was a gradual passage to its clear open seas over New York, from the great sea-marshes of the Salina period. The period is so named because its beds are well displayed in the Helderberg Mountains, south of Albany, beneath Devonian beds called the "Upper Helderberg."

The lower beds are designated the *Water-lime group;* they overlie directly the Salina beds, in New York, and appear as if a continuation of them. Moreover, they spread through the State, from the Hudson River to its western border, while the rest of the series does not reach west beyond Ontario County. The whole thickness in eastern New York is 400 feet. A single isolated summit of Lower Helderberg rocks, called Becraft's Mountain, stands just east of the Hudson River, near the city of Hudson; and another is Mount Bob, three miles to the northeast: these are evidently remnants of a great formation that once spread widely in that direction. Another isolated patch occurs near Montreal.

The Helderberg rocks outcrop also over a large area in western Ohio, and are continued thence into Indiana. They come out to view also in southern Illinois.

South of New York, along the Appalachian region, they extend through New Jersey, Pennsylvania, Maryland, and Virginia, increasing in thickness, being in all 500 feet or more on the Potomac; and, as in the North, they diminish westward.

The subdivisions of the formation observed in the Helderberg Mountains are for the most part undistinguishable out of New York State. The lowest rock, the *Water-lime*, retains its characters most widely, and has a thickness of 350 feet on the Potomac (Rogers). The

Water-lime is so called because used for making water- (or hydraulic) cement; it is a drab-colored or bluish impure limestone, in thin layers.

At Bernardston, Mass., a few miles west of the Connecticut (on the land of Mr. Williams), there is a Crinoidal limestone, which is proved by its large fossil Crinoids to be Lower or Upper Helderberg, probably the former. It underlies quartzyte and garnetiferous mica schist. The same formation, though without limestone, extends, as the author has ascertained, northeastward to South Vernon, where it includes staurolitic mica schist, hornblende rocks, quartzose, gneiss, and mica schist; and these rocks are the kinds characteristic of the Coös group of Hitchcock, which stretches northward through New Hampshire, east of the Connecticut. Near Littleton a limestone of the Upper Helderberg contains fossil corals and Brachiopods. Rocks of this era extend from Northern New Hampshire over Maine, to New Brunswick and Nova Scotia.

The following are the several New York subdivisions, beginning below, — 1. Tentaculite and Water-lime group, 150 feet in the Helderberg Mountains. 2. Pentamerus limestone, 50 feet in the Helderberg Mountains. 3. Catskill or Delthyris Shaly limestone. 4. Encrinal limestone. 5. Upper Pentamerus limestone.

An analysis of the Water-lime rock afforded Dr. Beck — Carbonate of lime 48·4, carbonate of magnesia 34 3, silica and alumina 13·85, sesquioxyd of iron 1·75, moisture and loss 1·70. One of the beds of the Water-lime strata, consisting of thin clinking layers, abounds in fossils called *Tentaculites*, and has been named *Tentaculite limestone.*

The *Pentamerus limestone* (No. 2), overlying the Water-lime, is so called from its characteristic fossil, *Pentamerus galeatus* (Fig. 462). It is compact, and mostly in thick layers. The *Catskill* or *Delthyris Shaly limestone* (No. 3) consists of shale and impure thin-bedded limestone, and, in many places in New York, abounds in the large fossil shell *Spirifer macropleura* Con. It extends as far west as Madison County, and is full of fossils. The *Encrinal limestone* (No. 4) is confined to the eastern part of the State. The *Upper Pentamerus* (No. 5), the upper layer, is of limited extent, but has many peculiar fossils: it is named from the *Pentamerus pseudo-galeatus* H. (Figs. 464, 465).

The Saliferous beds pass rather gradually into the Water-lime, — their upper layers becoming more and more calcareous, and containing some of the Water-lime fossils.

In Ohio, the rocks outcrop (owing to the extension northward of the Cincinnati uplift, p. 217) over a north-and-south region extending from the western portion of Lake Erie southward (Newberry), nearly to the Ohio river, and westward into Indiana. The rocks make part of the "Cliff limestone" of the Interior basin (so called because it stands in cliffs along the river valleys).

In West Tennessee, light-blue limestones of this period, abounding in fossils, occur in Hardin, Henry, Benton, Decatur, and Stewart counties. The maximum thickness is about 100 feet. In southern Illinois, there are beds of siliceous limestone underlying the Clear Creek limestone, the lower part of which Worthen refers to this period; they rest directly upon limestones of the Cincinnati or Hudson River age (the Cape Girardeau limestone of the Missouri Report), no Niagara limestone intervening (Worthen).

In the *Appalachian region* in Pennsylvania, the Water-lime group has, in the middle belt of the mountains, a thickness in some places of 350 feet, while in the southeast belt it is 50 to 200 feet; it thickens to the southwestward. The rest of the Lower Helderberg, consisting also of impure limestones, has a thickness of 100 feet or more in the middle belt, and 200 to 250 in the southeastern, which thickness is maintained along the Appalachian chain. (Rogers.) The beds have not been observed in East Tennessee.

In the *Eastern-border region*, at Pembroke, Me., in a granitic region, slates and hard sandstones occur, with many fossils; at other places in northern Maine, the rock is limestone. The Littleton, N. H., beds have afforded *Favosites basaltica*, a *Zaphrentis*, and *Pentamerus Knightii*.

The formation of Maine extends northeastward to Cape Gaspé, where there are 2,000 feet of limestones, the larger part referred to the Lower Helderberg by Logan, with the upper beds probably Oriskany.

In southern New Brunswick, rocks of this period occur as a continuation of those of Maine; also in northern New Brunswick; also in the Arisaig district, northern Nova Scotia, shales and limestone, which stretch around to East River of Pictou; also in the Cobequid Mountains, Nova Scotia.

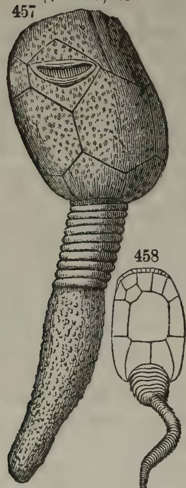
II. Life.

The rocks abound in fossils, beyond even the Niagara or Trenton: over 300 species have been named and described. Among them, there are the same families and genera as in the preceding periods, but with some marks of progress in new forms, and with a range of species almost completely distinct. Yet it has been noted, as a striking fact, that very many of the species of the Niagara period have their closely-related or representative species in the Lower Helderberg.

Figs. 457, 458.

457

458



CYSTIDEANS.— Fig. 457, Apiocystis Gebhardi; 458, Anomalocystites cornutus.

1. *Plants.*

Limestone strata seldom contain remains of plants; and, accordingly, little is known of the Botany of the Lower Helderberg period.

2. *Animals.*

Many Corals and Crinoids occur in the beds; and some of the latter are of remarkable size and beauty, — as *Mariacrinus nobilissimus* H., and other species of the same genus. The last known remains of the *Halysites*, or Chain-coral, occur in this formation. There were also a few species of *Cystids* (Figs. 457, 458).

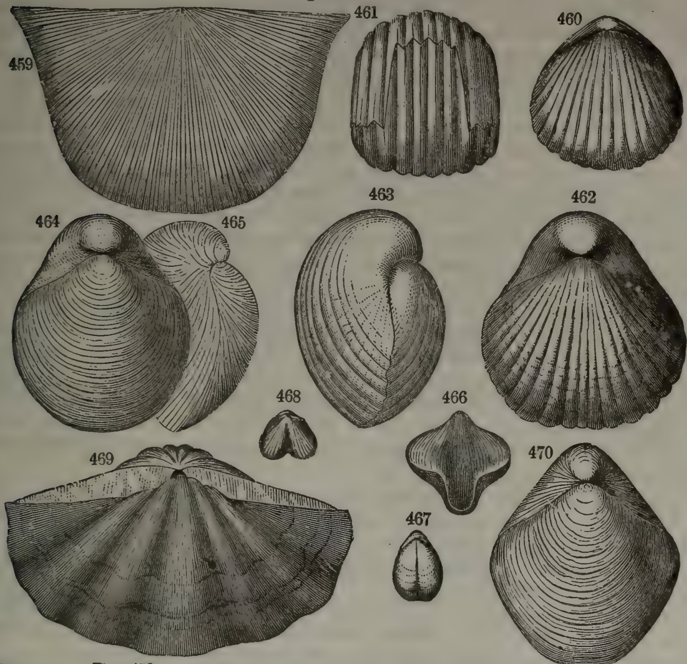
Among Mollusks, Brachiopods are far the most numerous, leading in numbers all other kinds of life. Figs. 459–470 represent some of the common kinds.

In the Water-lime, there occur vast numbers of a little, slender, straight shell, called *Tentaculites*, which have been supposed to be the shells of a kind of worm, of the Serpula family. Fig. 471 represents them, natural size; and 472, enlarged.

Trilobites were common still, and one of the species is the *Dalmanites*

pleuroptyx H., near Fig. 254 on page 174. Ostracoid crustaceans of large size, like Fig. 473, are abundant in some layers of the Water-

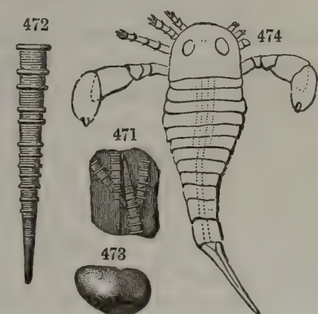
Figs. 459–470.



BRACHIOPODS. — Fig. 459, Hemipronites radiata; 460, 461, Rhynchonella ventricosa; 462, 463, Pentamerus galeatus; 464, 465, P. pseudo-galeatus; 466, Eatonia singularis; 467, Meristella sulcata; 468, Orthis varica; 469, Spirifer macropleura; 470, Meristella levis.

lime. Besides these Crustaceans, there was also a new kind, here making its first appearance in American rocks. One species of the group is the *Eurypterus remipes* of Dekay (Fig. 474). Unlike Trilobites, it has large jointed arms, and a body which resembles that of the Sapphirina and Caligus groups of modern Crustaceans. (Figs. 165, 166, on page 120, represent the female and male of a Sapphirina from existing seas.) Many specimens of this kind of Crustacean from the Water-lime have a length of a foot or more.

Figs. 471–474.



Figs. 471, 472, Tentaculites irregularis; 473, Leperditia alta; 474, Eurypterus remipes.

Characteristic Species.

1. Protozoans. — *Stromatopora.*

2. Radiates. — (*a.*) *Polyps.* — Among Corals, there are species of *Zaphrentis, Favosites, Halysites, Syringopora, Chætetes.* (*b.*) *Echinoderms.* — Group of Cystideans: Fig. 457, *Apiocystis Gebhardi* Meek, found in the Lower Pentamerus; Fig. 458, *Anomalocystites cornutus* H., a remarkable species from the same rock. Of Crinideans, there are species of the genera *Mariacrinus, Platycrinus, Edriocrinus, Aspidocrinus,* etc.

3. Mollusks. — *Brachiopods.* — Fig. 459, *Hemipronites* (*Strophomena*) *radiata* of the Catskill shaly limestone; 460, 461, *Rhynchonella ventricosa* H. of the Upper Pentamerus; 462, 463, *Pentamerus galeatus* H., of the Lower Pentamerus; 464, 465, *P. pseudo-galeatus* H., of the Upper Pentamerus; 466, *Eatonia singularis* H., of the Catskill Shaly; 467, *Meristella sulcata* H., of the Water-lime; 468, *Orthis varica* H., of the Catskill Shaly; 469, *Spirifer macropleura* H., ibid.; 470, *Meristella levis* H., ibid.

There are also Lamellibranchs of the genus *Avicula,* and others related; Gasteropods of the genera *Platyceras, Platyostoma, Holopea,* etc. Also the Pteropod, *Tentaculites irregularis* H. (Figs. 471, 472, the latter natural size).

4. Articulates, — (*a.*) *Trilobites.* — *Dalmanites pleuroptyx,* near Fig. 254; others of the genera *Calymene, Ceraurus, Asaphus, Homalonotus, Phacops, Lichas, Acidaspis, Proetus,* etc. (*b.*) Other *Entomostracans.* — Fig. 474, *Eurypterus remipes* Dekay, of the Water-lime, natural size, from a small specimen from the cabinet of E. Jewett. Several other species occur in the Water-lime; also species of the allied genus *Pterygotus* (Fig. 482 is a foreign species), and of the genus *Ceratiocaris.* Fig. 473, *Leperditia alta* H., an Ostracoid, abundant in the Water-lime; besides other *Leperditiæ,* and several species of *Beyrichia,* related Ostracoids.

The following is a list of characteristic species of the subdivisions: —

1. Water-lime. — *Meristella sulcata, Leperditia alta, Tentaculites irregularis,* various species of *Eurypterus* and *Pterygotus.*

2. Lower Pentamerus. — *Apiocystis Gebhardi, Rhynchonella semiplicata* H., *Pentamerus galeatus,* species of *Lichenalia?*

3. Catskill Shaly Limestone. — *Hemipronites radiata, H. punctulifera, Meristella levis, Eatonia singularis, Spirifer macropleura, Sp. perlamellosus* H. (formerly *rugosus*), *Platyceras ventricosum* Con., *Dalmanites pleuroptyx* H. (formerly *D. Hausmanni*).

4. Upper Pentamerus. — *Pentamerus pseudogaleatus, Rhynchonella ventricosa, R. nobilis* H., *Spirifer concinnus* H.

Atrypa reticularis and *Strophomena rhomboidalis* are among the few species of the Niagara period which occur in the rocks of the Lower Helderberg.

III. General Observations.

Geography. — In the Salina period, as already explained, the limestone-making seas of the Niagara period in New York had been succeeded by a great range of muddy flats and shallow basins; and, in the West, the basin had apparently become much contracted in area, judging from the limited extent of the Salina beds. Neither of these formations reaches to eastern New York.

In the Lower Helderberg period, which succeeds, there was a return of the conditions for making limestones; but, in striking contrast with the formations that preceded, the beds have their greatest thickness in *eastern* New York, and none occur in western. The Lower Helderberg limestones are mainly Appalachian formations; for even the New York part is directly in the range of the Appalachians of Penn-

sylvania. It is worthy of note that this limestone formation, of the later Upper Silurian, was the first limestone that was produced over the Appalachian region after the Lower Silurian. But the Trenton beds spread through the west as well as the east, while the Helderberg occur less extensively at the west; and in this the two periods are in contrast, the older limestone having the widest distribution.

It has been stated that the Lower Helderberg limestone occurs even *east* of the Hudson, overlying unconformably the Lower Silurian slates, its nearly horizontal beds constituting the summit of Becraft's Mountain and Mount Bob, near Hudson; and also that other patches of it exist near Montreal. Logan suggests that a conglomerate limestone filling a break in the rocks near Burlington, Vermont, may be Lower Helderberg, as the conglomerate closely resembles that near Montreal. Whatever the doubt with regard to the last mentioned locality, the other isolated beds are proofs of a former wide distribution of the Lower Helderberg limestone over Canada, and along the lower part of the western slopes of the Green Mountain chain.

4. ORISKANY PERIOD (8).

I. Rocks: kinds and distribution.

The Oriskany sandstone extends from central New York (the region of Oriskany, Oneida County) southwestward along the Appalachians, and spreads westward through Upper Canada and Ohio, into Indiana, Illinois, and Missouri. Unlike the Lower Helderberg beds, it thins out toward the Hudson River, becoming barely recognizable. The rock over these regions is mostly sandstone, often rough in aspect, but is partly limestone in the Mississippi basin.

In the Eastern-border region the rock is mainly limestone. It constitutes, in many places, the upper portion of the Silurian formation, lying between northern Vermont and Moosehead Lake in Maine, and between the latter and Gaspé on the Gulf of St. Lawrence, its characteristic fossils occurring at several localities over the region.

The Oriskany sandstone strata are passage-beds between the Silurian and Devonian.

The Oriskany sandstone was made the commencement of the Devonian by De Verneuil; but Hall has since referred it to the Upper Silurian, on the ground of the relations of its fossils. In New York, it consists either of pure siliceous sands, or of argillaceous sands. In the former case, it is usually yellowish or bluish, and sometimes crumbles into sand suitable for making glass. The argillaceous sandstone is of a dark brown or reddish color, and was once evidently a sandy or pebbly mud. In some places, it contains nodules of hornstone. The beds are often distinguished by their rough and hard dirty look (especially after weathering), and by the large coarse calcareous fossil shells, — species of Brachiopods. In some regions they are cherty. The sandstone appears on Lake Erie near Buffalo, and enters Canada at Waterloo, on the Niagara

River. It outcrops in Ohio, either side of the Lower Helderberg area, and extends thence into Indiana. In southern Illinois, there are 250 to 300 feet of siliceous limestones. In St. Genevieve County, Missouri, the rock is a limestone (Shumard).

The Nova Scotia strata of this epoch occur at Nictaux and on Moose and Bear rivers. They include a thick band of fossiliferous iron-ore, which is an argillaceous deposit at Nictaux, but, owing to partial metamorphism, is magnetic iron-ore, and partly specular, on Moose River. At Gaspé, it includes the upper part of the limestone formation, and probably the lower part of the sandstone beds, a *Rensselaeria* having been found 1,100 feet above the base of the sandstones.

II. Life.

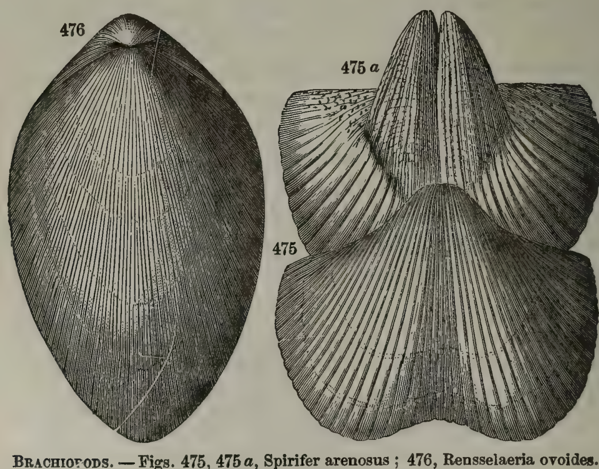
1. *Plants.*

Sea-weeds are not uncommon. No remains of land-plants have yet been observed in the beds of New York, or at the West. But, in the upper limestones of Gaspé, remains of a small species of the Lycopodium or Ground-Pine tribe occur, which have been named by Dawson *Psilophyton princeps*, a figure of which is given on p. 258. The Lycopods are Cryptogams, or flowerless plants, but belong to the highest division of Cryptogams, that of Acrogens. The plant grew to about the same height with the common American species *Lycopodium dendroideum.* (For further description, see p. 257.)

2. *Animals.*

The most common Mollusks are the coarse *Spirifer arenosus* H. (Fig. 475), and the *Rensselaeria ovoides* H. (Fig. 476.) The rock is

Figs. 475–476.



Brachiopods. — Figs. 475, 475 *a*, Spirifer arenosus ; 476, Rensselaeria ovoides.

often made up of these large fossil shells crowded together, or contains their moulds, with the cavities the shells once occupied. Fig.

475 *a* represents a cast of the interior of *Spirifer arenosus*. There are also many other species of *Brachiopods*, and a number of *Lamellibranchs*, *Gasteropods*, and *Cephalopods*. Among the Gasteropods, the shells of *Platyceras* are in some places very numerous; they are a thin shell of a floating Mollusk, related to the delicate *Ianthina* of modern seas; as stated by Hall, they often occur in the Maryland beds, in groups, as if drifted together by the winds or gentle currents. Crinoids are rare fossils in New York, but common in Maryland. No Fishes have yet been found in the beds.

The Crinoids in Maryland include a number of fine species of the genera *Mariacrinus*, *Edriocrinus*, and others, besides three species of *Cystideans*, and among them one of the peculiar genus *Anomalocystites* (allied to Fig. 458). The rock in some places contains a wonderful profusion of shells, although the number of species is small.

Rensselaeria ovoides, *Spirifer arenosus*, together with the *Cauda-galli fucoid* (Fig. 484, p. 255) and three species of *Chonetes*, occur in the upper 500 feet of the Gaspé limestone, as determined by Billings, associated with *Favosites Gothlandica* Lam., *F. basaltica* Goldf., *F. cervicornis* De Blainville, two species of *Zaphrentis*, *Strophomena rhomboidalis*, *S. Becki*, *S. perplana* Con., *Leptocœlia concava* H., *L. flabellites* H., *Eatonia peculiaris* H., *Atrypa reticularis*, *Meristella lævis* H., species of *Modiolopsis*, *Avicula*, *Murchisonia*, *Loxonema*, *Orthoceras*, *Phacops*, *Proetus*, also *Dalmanites pleuroptyx*, etc. The fucoid extends down 800 feet, and is abundant. At Parlin Pond, in northern Maine, there occur *Rensselaeria ovoides*, *Leptocœlia flabellites*, *Spirifer arrectus* H., *S. pyxidatus* H., *Strophomena* (*Hemipronites*) *magnifica* H., *Rhynchonella oblata* H., *Orthis musculosa* H., *Dalmanites pleuroptyx*, species of *Chonetes*, *Modiolopsis*, *Cyrtodonta*, *Avicula*, *Murchisonia*, *Platyostoma*, *Orthoceras*.

The ribs of some Oriskany *Spirifers* have a peculiarity observed in only one other American *Silurian* species (of the Niagara epoch), but in Europe not known before the *Devonian* age, — which is, that they subdivide dichotomously, instead of being simple. The shell, in the genus *Rensselaeria* Hall, contains a loop-like arm-support, a little like that in *Terebratula*, but it is only curved, instead of bent, and has a spade-shaped termination.

III. General Observations.

The Oriskany sandstone is another of the arenaceous rocks ranging from central New York to the southwest, along the Appalachian region, and thus serving to define the old Appalachian sand-reef. As in other cases, the rock thickens on going from New York to the southwestward. The fossils and the distribution of the formation over the State of New York, seem to point to the existence at this epoch of inland waters opening into the ocean to the southeast, — as might have existed if the Green Mountain region (as before in the Upper Silurian era) were out of water, and if also the Archæan of northern New Jersey (see p. 150), the proper continuation of the Green Mountains, were an island or reef in the sea. The muddy and sandy bottom of the bay would have given the shells a fit place for growth. To the south, as the fossils in Maryland and beyond show, the accumulations were those of an open bay or coast, where there were at least

purer waters. We may hence conclude that the Green Mountain region was a north-and-south island or peninsula, lying between seas of the Connecticut valley and those of New York, and having the St. Lawrence channel on the north. The region of Appalachian subsidence, instead of including the Green Mountains, as in the early Lower Silurian era, extended northward, in the direct line of the Alleghanies, over the southern half of central New York, as in parts of the Upper Silurian; for this is indicated by the position of the sandstone.

2. FOREIGN UPPER SILURIAN.

Rocks. — The rocks of the Upper Silurian are widely distributed over the globe, though less universal than those of the Lower Silurian. They occur in Great Britain, Scandinavia, Russia, Germany, Bohemia, and Sardinia, but have not been identified in France or Spain; also in Asia, Africa, and Australia. They sustain the principle that the earlier formations are in general of continental range. They seem on a geological map to cover but small areas, but only because they are concealed by later formations.

The Upper Silurian Rocks of Great Britain comprise, commencing with the earliest: —

1. The *Upper Llandovery sandstone* of South Wales, about 900 feet in thickness, which generally lies unconformably on the Lower Silurian, and its equivalents. The May Hill sandstone of Shropshire, which was first so named, and shown to be Upper Silurian, by Sedgwick. These sandstones terminate in the Tarannon shales, 600 feet where thickest. This group is regarded as the equivalent of the Medina and Clinton groups.

2. The *Wenlock Group*, consisting of the gray and black Wenlock shales, 1,400 feet thick, and the Wenlock limestone, 100 to 300 feet thick. They are well exposed between Aymestry and Ludlow, and along Wenlock Edge to Bethel Edge; also near Dudley, where the *Woolhope limestone*, a lower part of the series, 50 feet thick, overlies the Llandovery sandstone. The limestone is full of fossils, or rather is made up of them closely compacted; and much of it looks as if it were a deep-water formation. Its American equivalent is the Niagara group.

3. The *Ludlow Group*, made up of (1) the Lower Ludlow rock of Shropshire, consisting of layers of shale and impure sandstones or mudstones, 900 feet thick; (2) the Aymestry limestone, an impure limestone, 150 feet thick; (3) the Upper Ludlow rock, a shaly or impure sandstone, much like the Lower Ludlow, 900 feet thick. The *Tilestones* are series of red and gray sandstones, marlytes and red conglomerates, 1,000 feet thick, regarded as passage-beds to the Devonian. These Ludlow beds and the Tilestones are apparently equivalents of the later half of the American Silurian. There are one or two thin *bone-beds* between the Tilestones and the Ludlow, consisting of remains of fishes and crustaceans. The limestone of the Upper Silurian fails in North and South Wales, and in some parts even the distinction of Wenlock and Ludlow cannot be made out.

In Cumberland or Northern England, the Coniston grits, Ireleth slates, and Kendal group correspond to the above groups 1, 2, 3. In Scotland, the lower Sandstone is represented in Southern Ayrshire, and the Wenlock in the Pentland Hills. Upper Silurian rocks occur also in Ireland.

In Scandinavia, the limestones and sandstones of Gothland represent the Niagara, and the Calciferous flags and Upper Malmö group the Lower Helderberg. In Bohemia, the rocks include the limestones and schists of Barrande's formations E, F, G, H.

Life. — 1. *Plants.* — Besides sea-weeds, there are the remains of terrestrial plants. In the Upper Ludlow beds, occur seed-vessels called *Pachytheca* by Hooker, and also fragments of stems, supposed to be those of Lycopods (Ground Pines) related to the *Psilophyton.* In Germany at Lobenstein, and at Hostin in Bohemia, Lycopods of the *Lepidodendron* family occur — a kind having the bark marked regularly with scars where the leaves have dropped off, similar to those on a young dry branch of a spruce. The word *Lepidodendron* is from λεπίς, *scale*, and δένδρον, *tree*, the bark, owing to the scars over it, often looking as if scale-covered. The species are referred to the genus *Sagenaria.* These plants, like modern Lycopods, had much of the habit of the spruce or pine tribe. For figures see pages 323, 324.

Besides these *flowerless* species (Cryptogams), others of genera of the Pine tribe — the lowest division of flowering plants (Phenogams) — are supposed by Dawson to have existed, he referring pieces of carbonized wood in the Upper Ludlow beds to the genus *Prototaxites* (so named from πρῶτος, *first*, and *taxus*, *yew-tree*). Carruthers considers the plant a sea-weed.

2. *Animals.* — The range of Invertebrate animal life and the general types are similar to those of America, while the species are for the most part different.

A few species are represented in Figs. 477 to 482. Figs 477, 477 *a* represent a Cyathophylloid coral *Omphyma turbinatum* M. Edw., of the Wenlock, reduced one-half; 478, a section of another coral, a species of *Cystiphyllum*, from the same beds; 479, a peculiar Crinoid, *Crotalocrinus rugosus* Miller, from the Wenlock; 480, the *Pentamerus Knightii* Sow., a characteristic fossil of the Aymestry limestone; 481, a Lamellibranch, *Grammysia cingulata* Morris, of the Dudley limestone: 482, the Crustacean, *Pterygotus bilobus* Salter, from the upper Ludlow; and 482 *a*, one of the jaws. The earliest species of these *Pterygoti* occur in the upper beds of the Upper Llandovery, the lower part of the Upper Silurian; while in North America none have been found below the Lower Helderberg.

Besides Invertebrates, there were the earliest Vertebrates — Fishes. The first (*Pteraspis*) is from the lower Ludlow. Fig. 483 *a* represents *Pteraspis Banksii* Huxl. & S., a head-shield, related to the following. Fig. 483 *b* is the head-shield of a *Cephalaspis* — so named from the Greek for a shield-like head; a complete animal, but different in species, is shown on page 286. Fig. 483 *d*, represents probably part of the jaw-bone of a *Cephalaspis.*

Other fishes were of the shark tribe. Fig. 483 *c*, represents a spine from the margin of the fin of one of them; and 483 *e*, two of the minute pieces much magnified (the natural size is shown in the upper

of the three figures) which constituted the hard rough skin (shagreen) of a shark. A number of Upper Silurian fishes have been described,

Figs. 477–482.

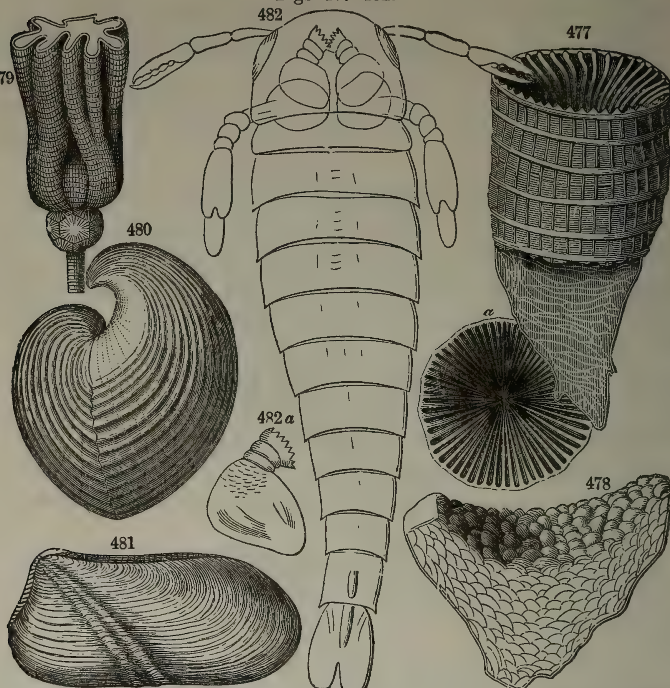
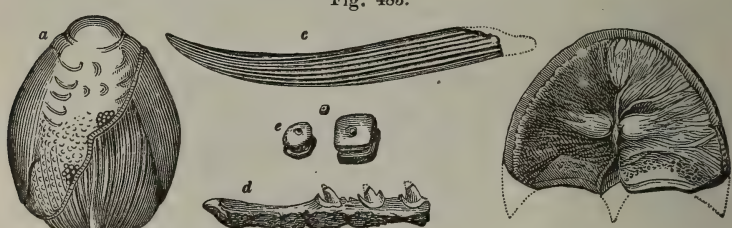


Fig. 477, Omphyma turbinatum; 478, Cystiphyllum Siluriense; 479, Crotalocrinus rugosus; 480, Pentamerus Knightii; 481, Grammysia cingulata; 482, 482 *a*, Pterygotus bilobus.

from the rocks of Russia and Bohemia, including species of *Coccosteus* and *Pterichthys*, and the fin-spines of sharks; figures of other species

Fig. 483.



Fishes. — Fig. 483 *a*, Pteraspis Banksii, tail-shield; 483 *b*, Cephalaspis Murchisoni, inside of head-shield; *c*, spine of Onchus tenuistriatus; *d*, Plectrodus mirabilis; *e*, Shagreen pieces of Thelodus parvidens.

of these genera are given on p. 285. For further remarks on the subdivision to which these fishes belong, see page 264.

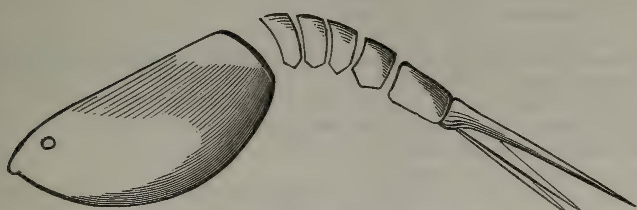
Characteristic Species.

1. *Upper Llandovery.—Petraia bina* Phillips, *Atrypa hemisphærica, Rhynchonella neglecta, R. angustifrons* S., *R. Wilsoni Strophomena arenacea* (or *concentrica* Portl.), *S. compressa* S., *Pentamerus globosus* Sow., *P. oblongus* Sow., *Orthis lata* Sow., *Lyrodesma cuneata* Phil., *Pterinea sublævis* M'Coy., *Murchisonia angulata* Sow., *Cyclonema quadristriatum*, Phil., *Raphistoma lenticularis* Sow.

2. *Wenlock group.* — *Petraia bina, Cyathophyllum truncatum* Linn., *Omphyma turbinatum* (Fig. 477), *Favosites Gothlandica, F. alveolaris, Halysites catenulata, Heliolites Grayi* E. & H., *H. interstincta, Syringopora bifurcata* Lonsd , *Cystiphyllum Siluriense* Lonsd. (Fig. 478), *Stenopora fibrosa, Ptilodictya scalpellum* Lonsd., and many other Bryozoans, *Actinocrinus pulcher* S., *Crotalocrinus rugosus* (Fig. 479), *Hypanthocrinus decorus* Phill., *Marsupiocrinus cœlatus* Phill., *Atrypa reticularis, Orthis elegantula, Rhynchonella Wilsoni, Pentamerus galeatus, Strophomena rhomboidalis, Spirifer plicatellus, Modiolopsis antiqua* Sow., *Conocardium æquicostatum, Pterinea retroflexa, Grammysia cingulata* (Fig. 481), *Orthoceras annulatum* Sow., *Tentaculites ornatus* Sow., *Acidaspis Barrandii* Ketley, *Calymene Blumenbachii, Homalonotus delphinocephalus, Lichas Anglicus, Phacops caudatus, Encrinurus variolaris* Brngt. The earliest remains of *Cirripeds* yet known occur in the Wenlock limestone.

3. *Ludlow Group.* — *Graptolithus priodon* Bronn., *Cyathaxonia Siluriensis* M'Coy, *Pentamerus Knightii* (Fig. 480), *Rhynchonella nucula* Sow., *R. pentagona* Sow., *Lingula Lewisii* Sow., *Modiolopsis complanata, Pterinea retroflexa, Avicula Danbyi* M'Coy, *Bellerophon expansus* Sow., *Loxonema sinuosum* Sow., *Conularia subtilis* S., *Orthoceras bullatum, Calymene Blumenbachii, Encrinurus punctatus* Wahl., *Homalonotus Knightii* König, *Lichas Anglicus* Beyrich, *Phacops caudatus* Brünn, several species of *Eurypterus* (the earliest in the Upper Ludlow), *Pterygotus bilobus* (Fig. 482), and other species (one from the Upper Llandovery), *Ceratiocaris inornatus* M'Coy, *C. ellipticus* M'Coy

Fig. 484.



Ceratiocaris.

Salter has illustrated the form of the *Ceratiocaris* by Fig. 484: the length is sometimes four inches or more.

In the Ludlow group, mostly its upper part, occur remains of the earliest known fishes of British seas, among which are the species, *Onchus tenuistriatus* (Fig. 483 *c*), *Plectrodus mirabilis* Ag. (Fig. 483 *d*), (perhaps *Cephalaspis*), *P. pustuliferus* Ag., *Pteraspis Banksii* Huxley & Salter (Fig. 483 *a*), *Pt. truncatus* H. & S., species of *Sphagodus.* A species of *Pteraspis* occurs in the Lower Ludlow, and this therefore is the earliest form of fish known. This genus is related to *Cephalaspis.* There are also in the same rocks Coprolites from some of these Fishes, containing fragments of the shells of the Mollusks and Crinoids on which they fed. Remains of Fishes have also been found in the upper part of the Upper Silurian of Russia and Bohemia. The *Pteraspis* has been referred to Crustaceans.

The following tables show the distribution in other countries of some species of the Niagara and Lower Helderberg periods.

1. *American Clinton and Niagara Species occurring elsewhere.*

Stromatopora concentrica, Great Britain (Dudley), Sweden, Russia, Eifel.
Halysites catenulata, Great Britain (Llandeilo, Dudley, Aymestry), Norway, Sweden Russia, Eifel.
Heliolites pyriformis, Great Britain (Wenlock, Aymestry), France, Sweden, Russia, Eifel.
Limaria fruticosa, Great Britain (Dudley, Aymestry), Russia.
Limaria clathrata (?), Great Britain (Dudley), Russia.
Ichthyocrinus levis Con. (?), Great Britain (Dudley).
Eucalyptocrinus decorus, Great Britain (Dudley).
Orthis elegantula, Great Britain (Wenlock), Gothland (in Sweden).
Orthis hybrida Sow., Great Britain.
Orthis biloba, Great Britain (Dudley), Gothland.
Orthis flabellulum, Great Britain (Bala.)
Leptæna transversalis, Great Britain, Gothland.
Strophomena rhomboidalis (formerly *Leptæna depressa* and *Stroph. rugosa*), Great Britain (Dudley, Aymestry), Sweden, Russia, Belgium, Eifel, France, Spain.
Spirifer crispus Hising., Great Britain (Llandeilo, Dudley), Gothland.
Spirifer radiatus, Great Britain (Dudley).
Spirifer sulcatus Hising. (?), Great Britain (Dudley).
Nucleospira pisum, Great Britain (Wenlock and in Scotland).
Atrypa reticularis, Great Britain (Wenlock), Gothland, Germany, Russia (Urals, Altai).
Merista (*Rhynchonella*) *nitida*, Great Britain and Gothland.
Rhynchonella bidentata, Great Britain (Wenlock).
Rhynchonella cuneata, Great Britain (Wenlock), Gothland.
Rhynchonella plicatella Dalm., Great Britain (Wenlock, Aymestry).
Rhynchonella Wilsoni, Great Britain (Wenlock).
Rhynchospira ? (Atrypa) aprinis, Russia.
Pentamerus brevirostris H., Great Britain.
Pentamerus oblongus, Great Britain (Wenlock).
Pentamerus levis, Great Britain (Wenlock). —*P. Knightii*, Great Britain (Ludlow).
Anastrophia interplicata, Great Britain.
Orthoceras implicatum, Great Britain (Ludlow), Gothland.
Orthoceras annulatum, Great Britain (Wenlock).
Orthoceras virgatum, Great Britain.
Orthoceras undulatum, Great Britain, Eifel.
Illænus (*Bumastis*) *Barriensis*, Great Britain (Dudley).
Phacops limulurus (?), Great Britain (Dudley), Bohemia, Sweden.
Ceraurus insignis, Bohemia.
Calymene Blumenbachii, Great Britain (Bala, Wenlock), Sweden, Norway, Bohemia, France.
Homalonotus delphinocephalus, Great Britain (Dudley).
Proëtus Stokesii Murch., Great Britain (Dudley).

2. *American Lower Helderberg Species occurring elsewhere.*

Strophomena rugosa, Great Britain (Dudley, Aymestry), Gothland, Russia, Eifel, France, Spain.
Atrypa reticularis, Great Britain (Wenlock), Sweden, Russia (Urals, Altai), Bohemia.
Dalmanites nasuta, Great Britain, Sweden, Russia.
Eurypterus remipes, Russia (island of Oesel, according to Keyserling).
Pentamerus galeatus, Great Britain (Aymestry, Dudley, Ludlow), Eifel.

There are a number of other species closely like European, but they are regarded by Hall as distinct.

3. *Arctic American Upper Silurian Species occurring elsewhere.*

Stromatopora concentrica, Great Britain, Eifel.
Halysites catenulata, Great Britain, Norway, Sweden, Russia, United States.
Favosites Gothlandica, Great Britain, Sweden, United States.
Favosites polymorpha, Great Britain, France, Belgium, Eifel.
Receptaculites Neptuni, Great Britain, Belgium, Eifel, United States.
Orthis elegantula, Great Britain, Gothland, Russia, United States.
Atrypa reticularis, Great Britain, Gothland, Urals, Altai in Siberia, United States.
Pentamerus conchidium Dalman, Gothland.
Rhynchonella (?) *sublepida* (?) De Verneuil, Urals.
Encrinurus levis (?) Angelin, Gothland.
Leperditia Baltica Hisinger, Gothland.

A considerable number of species in the British Lower Silurian pass into the Upper Silurian. They are found mingled in the intermediate Llandovery formations; which, although classed with the Upper Silurian, contain between 40 and 50 species that occur also below.

Barrande has found nearly 2,800 species of fossils in the Bohemian Silurian basin, including the Primordial strata. The limestone E abounds in organic remains; and among them are 400 species of Cephalopods, and 183 species of Trilobites (of the genera *Calymene*, *Acidaspis*, *Ceraurus*, *Cyphaspis*, *Lichas*, *Phacops*, *Harpes*, *Bronteus*, and *Proëtus*). Barrande regards this as the culminating period for the Trilobite race. Limestone F also contains 88 species of Trilobites, and of the same genera, associated with a profusion of Brachiopods. In G, there are many Goniatites and other species, which show that, while the strata are intimately connected with E and F physically, and in their fossils, the period probably corresponds in part with the early Devonian. Besides 56 species of Trilobites of the above genera, there are others of the Devonian genus *Dalmanites*. In Bohemia, 57 Lower Silurian species pass into the Upper Silurian.

A list of the genera common to the American and European continents would show almost a complete identity, and the same system of progress from the Lower Silurian onward. In each, the genera *Spirifer* and *Chonetes*, among the Brachiopods, were added to *Orthis*, *Leptæna*, and *Atrypa*; *Halysites* (Chain-corals), *Favosites*, and *Cyathophyllidæ* became abundant; *Crinoids* were greatly multiplied; and the *Eurypterus* group, or Cyclopoid Crustaceans, commenced a new line among the Articulates; while Graptolites, so common in the Lower Silurian, were few in species and numbers.

The number of Silurian species described, up to 1872, according to Barrande, is as follows: —

Sponges and other Protozoans	153	Bryozoans	478
Polyp Corals	718	Brachiopods	1,567
Echinoderms (Crinoids, etc.)	588	Lamellibranchs	1,086
Worms	185	Heteropods and Pteropods	390
Trilobites	1,579	Gasteropods	1,316
Other Crustaceans (including some Cirripeds)	348	Cephalopods	1,622
		Fishes	40

Which, with 4 of uncertain relations, make in all 10,074 species.

3. OBSERVATIONS ON THE UPPER SILURIAN.

1. General features. — Fresh-water lakes and rivers, fresh-water deposits, and land or fresh-water animal life, continue unknown through the American records of the Upper Silurian, as thus far investigated. Such rivers and lakes probably existed, as it is certain there was dry land; but they have left nothing that survived subsequent changes.

It is barely possible that some of the Mollusks may have lived in fresh waters; but the remains are so mingled with species that are obviously salt-water types that it cannot be proved to be true of any.

2. Individuality of the Eastern-border region in American geological history. — Some general facts bearing on this subject are mentioned on page 160. The individuality of the region is illustrated most conclusively by the life of the waters, as shown by Salter and Billings.

Thus, there are, in the beds of this region of the Primordial and Canadian periods, *Salterella rugosa* Billings, closely like the Scottish; *S. Maccullochi*, Salter; *Kutorgina cingulata* B., said by Davidson and Hall to occur in the Lingula flags; *Acrotreta gemma* B., very near *A. subconica* Kutorga; four species of *Piloceras*, a genus described from Scotland, but not known in the United States; *Holometopus Angelini* B., very near *H. limbatus* Angelin, of Sweden; *Nileus macrops* B., *N. scrutatus* B., *N. affinis* B., all closely allied to *N. armadillo* of Dalman; *Harpides Atlanticus*, very near Angelin's *H. rugosus* of Sweden. In the beds of Cincinnati group age, there are *Ascoceras Canadense* B., *A. Newberryi* B., and *Glossoceras desideratum* B., not found in the United States. In the Upper Silurian, there are, as shown by Salter, the British species *Rhynchonella Wilsoni* Sow., *Grammysia triangulata* Salter, *G. cingulata* His., *Platyschisma Helicites* Sow., *Acroculia Haliotis* Sow., *Bellerophon expansus* Sow., *B. carinatus* Sow., *O. bullatum* Sow. (?), *O. ibex* Sow., *Homalonotus Knightii* König, *Phacops Downingii* Salt., to which Billings adds *Rhynchonella Stricklandii* Sow., and *Lituites Americanum* B., very near, if not quite identical with *L. giganteum* Sow. Mr. E. Billings, who furnished this work the above list of species, adds that, through the Primordial and Canadian periods, there is a decided *European* tinge in the life; but in the Trenton period its character was peculiarly *American*. Then in the Cincinnati epoch there was again a European tinge, which increased in strength through the Upper Silurian.

3. Conditions of the North American Continent. — The survey of the successive formations of the Upper Silurian teaches that the geological changes in progress, like those of the earlier Silurian, operated widely over the continent. The causes in action were not making a mere edging to the continent, as in Tertiary times, but were building up the very continent itself by wide-spread accumulations of limestone, sands, and clays.

Moreover, the continental seas were not the ocean's bed, although they may, over wide areas at times, have exceeded 500 or 1,000 fathoms in depth. In many of the rocks, the ripple-marks of some layers, rill-marks of others, and cracks from sun-drying of others, often in the same stratum, prove the shallowness of the water over great regions, and a wide expanse of exposed beaches and marshes elsewhere. The beds of iron ore in the Clinton group, which have great extent, are other proof of wide-spread marshes over the country, since such deposits cannot form in the open sea. The brines of the Salina period again mark a time of salt marshes or inland salt lakes in New York.

The continent still included comparatively little permanent dry

land, and that was mainly to the north. It had enlarged somewhat since the Lower Silurian era; but the greater part of the United States was yet to be completed, by the deposition of the Devonian, Carboniferous, and later beds.

Shales and sandstones prevailed in the East, from the vicinity of the Archæan of New York southwest along the Appalachian region. But, in the west, the rocks of the Upper Silurian are mainly limestones; for the Niagara limestone is widely distributed in the Interior basin; and even in the Oriskany period, the beds are partly calcareous. The West was therefore in certain parts still making limestones, while the East interposed between its limestones extensive clay and sand deposits. The limestones of the West prove that there were but slight changes of level there during the long era when each stratum was forming; for, if great, they would have resulted in an extermination of the life, and a change, therefore, in the character of the limestone. At the same time, the great thickness of the argillaceous beds and sandstones of the East indicate great oscillations over the Appalachian region; during the Niagara period, they amounted, in Pennsylvania, to at least 500 feet in the Oneida epoch, 1,500 feet in the Medina, over 2,000 feet in the Clinton, 1,500 feet in the Niagara and Salina, and 500 in the Lower Helderberg, — in all 6,000 feet. In the Salina period, the subsiding area stretched up into New York, west of its centre; for it was there that the Salina beds were formed to a thickness of 1,000 feet, with evidence in many parts of shallow-water origin.

After the Salina period closed, limestones (the Lower Helderberg) were formed, some hundreds of feet thick, over the Hudson River valley, and probably all the way to Montreal, showing that the sea had again free access over eastern New York. East of the Green Mountain region also, there was probably salt water and some limestone making, along a large part of the Connecticut valley, and over much of the country thence to the St. Lawrence Gulf.

The conclusion cited from Mr. Billings, on page 250, that the Trenton period, in the region of the Gulf of St. Lawrence, fails of that commingling of European species which occurs in the period preceding and those following, accords with the fact that the Trenton limestone was eminently continental; it extending across the continent, even over the Appalachian region; and it sustains the conclusion that the Trenton limestone was made in an interior sea, and hence that, to the north, the outside barrier of that sea lay to the east of the present coast line, and thus prevented the introduction of British species. But in the following Cincinnati period there was a change which resulted in making the Appalachian region again a region of

shales and sandstones, and this fact, together with the new incursion of British species, is evidence that this eastern coast-barrier had dipped down beneath the ocean again; while the additional fact that the rocks of the same Atlantic border, which follow the Trenton, in the Upper Silurian era, are mainly limestones, would seem to prove that the barrier was only partly submerged.

Life. — The closing period of the Lower Silurian gave the first positive evidence of the existence of terrestrial plants in the world. As stated in connection with the Archæan, on pp. 157, 158, the fact that Lichens are not found fossil, nor the destructible Fungi, is no evidence that these classes of terrestrial vegetation were not also well represented. Considering the millions of years that passed in the course of the Lower Silurian and the first half of the Upper Silurian (nearly half of all geological time from the commencement of the Primordial onward), and the numberless chances for the burial of a drifted leaf, or broken stem, or a whole uprooted plant, if any such existed along the sea-shores, or in valleys which poured streams into the continental seas, the absence of remains of land plants had appeared until 1878 to be strong presumptive evidence that they did not exist. But some few specimens since observed show that the land of the Trenton period had its Ferns and Lycopods like the Devonian and Carboniferous eras. Such plants suggest that there were also species of terrestrial articulates; and they may yet be found. We have no right to suppose Mosses to have then existed, since none is known from the Devonian and Carboniferous beds.

The animals of the Upper Silurian, found fossil in American rocks, are all Invertebrates, like those of the Lower Silurian, and similar in general types. The Cephalopods are the highest species among Mollusks, and the Trilobites or Eurypterids among Crustaceans. But, in Great Britain and Europe, the existence of Fishes is made certain by various fossils; and these Fishes were either of the tribe of Sharks or of that of Ganoids.

Among the Invertebrates, there was constant change, some groups beginning, others expanding to their climax, and others disappearing. Graptolites, which passed their climax in the Lower Silurian, had comparatively few species in the Upper. Crinoids and Corals were brought out in various new forms, and of increasing variety. The Chain corals (*Halysites*) are an example of a genus that ended in the Upper Silurian, while the Favosites and Cyathophylloids are more multiplied in after time.

Mollusks were still most abundantly represented by Brachiopods. The genera *Spirifer*, *Athyris*, *Chonetes*, *Rensselaeria*, and others, were added to *Lingula*, *Orthis*, *Leptæna*, *Rhynchonella*, *Atrypa*, etc., of the Lower Silurian; at the same time, *Orthis* had lost its preëminence, and was of few species. The Lower Silurian Brachiopods have no bony arm-supports internally, excepting those of *Atrypa* and *Rhynchonella*. In both *Spirifer* and *Atrypa*, these supports were long and rolled spirally. The genus *Spirifer* commenced with narrow species, little broader than high; but in the later part of the Upper Silurian they were already much wider, though not as extravagantly so as in many species of the Devonian and Carboniferous. In the Niagara occurred the

first species of that division of the genus *Spirifer* in which the ribs of the shell are bifurcated; a kind that afterward became common.

The Lamellibranchs and Gasteropods were few, compared with Brachiopods; and, in both groups, the species were mostly siphonless; that is, the Gasteropods had the aperture without a beak, and the Lamellibranchs, with the exception of the Cardium family, had the pallial impression entire (Fig. 153). The species of Lamellibranchs were mostly of the *Mytilus*, *Avicula*, *Arca*, and *Cardium* families; those of the Heteropods and Gasteropods, mainly of the *Bellerophon* and *Trochus* families.

The *Tentaculites* had their climax in the Upper Silurian, occurring in great numbers in some of the rocks; after this, they were comparatively rare.

Among Cephalopods, the *Orthocerata*, while common, were neither so large nor so numerous as in the Lower Silurian. The genus *Ormoceras* — with large beaded siphuncle — ceased with the Niagara period. Both the straight and the curved or coiled shells had the partitions simply arched, and not plicate as in after-time.

The *Conulariæ* were more numerous and larger than before.

The subkingdom of Articulates, as far as knowledge from fossils goes, still embraced only the water-types of Worms and Crustaceans. Trilobites were multiplied in genera, — *Homalonotus*, *Phacops*, and others being added to *Calymene*, *Agnostus*, *Asaphus*, *Illænus*, *Lichas*, *Acidaspis*, and *Dalmanites*, etc., of the Lower Silurian. The bivalve Crustaceans, or Ostracoids, are very common. In the *Eurypterus* and *Pterygotus* (Fig. 461), there is a new step in the development of the Crustacean type, and, in the *Ceratiocaris*, an advance in still another direction. Yet the class of Crustaceans had not made progress beyond its lowest order, that of Entomostracans, — except it be that the earliest group, that of Trilobites, overstepped these bounds at the very beginning (p. 123). The Ostracoids were precursors of the modern Ostracoids; the Ceratiocarids, of the modern typical Cyclopoids; and the Eurypterids, of other Cyclopoids of flattened forms. But while precursors in time, many of the species of these groups were gigantic compared with the largest of those of the present day, exceeding the latter ten to fifty times in lineal dimensions; and it is not easy to prove that the smaller moderns are in any way their superiors in grade. While the middle of the Silurian age was the time of greatest expansion for the group of Trilobites, the closing period of it, with the early Devonian, appears to have been the time of culmination of the Entomostracan order.

Extinction of species. — The number of Upper Silurian species thus far described from the American rocks is about 3,500, which is at least 500 short of the number existing in collections. There is no evidence that a species existed in the later half of the Upper Silurian that was alive in the later half of the Lower Silurian. A number of species are continued into the Devonian; but these disappear long before the close of that age.

Genera of existing seas. — To the list of existing genera, no additions are made in the course of the Upper Silurian. All but *Lingula* (?), *Discina*, *Nautilus*, *Rhynchonella*, *Pleurotomaria*, and *Crania*, become extinct.

Climate. — There is no evidence that the climate of America included frigid winds or seas. The living species in the waters between the parallels of 30° and 45° were in part the same with, or closely related to, those that flourished between the parallels of 65° and 80°. (See pages 221 and 230.) From this life-thermometer we learn only of warm or temperate seas.

II. AGE OF FISHES, OR DEVONIAN AGE.

The Devonian formation was so named by Murchison and Sedgwick, from Devonshire, England, where it occurs, and abounds in organic remains. In America, and also in other countries, the beds pass into those of the Silurian by an easy transition.

1. American.

The periods and epochs in the American Devonian, as deduced from the series of rocks laid down by the New York geologists, are the following, commencing above: —

4. CATSKILL PERIOD (12) . . .	Catskill Red Sandstone (12).
3. CHEMUNG PERIOD (11) .	2. *Chemung Epoch* — Chemung group (11 *b*). 1. *Portage Epoch* — Portage group (11 *a*).
2. HAMILTON PERIOD (10) .	3. *Genesee Epoch* — Genesee beds (10 *c*). 2. *Hamilton Epoch* — Hamilton group (10 *b*). 1. *Marcellus Epoch* — Marcellus group (10 *a*).
1. CORNIFEROUS PERIOD (9).	3. *Corniferous Epoch* — Upper Helderberg group (9 *c*). 2. *Schoharie Epoch* — Schoharie grit (9 *b*). 1. *Cauda-galli Epoch* — Cauda-galli grit (9 *a*).

The beds of the first period are sometimes designated the Lower Devonian, and those of the second, third, and fourth periods, the Upper Devonian. The Corniferous period was the great limestone-making period of the Devonian age in America. The rocks of the succeeding periods (Upper Devonian) are mostly shales or sandstones, with only subordinate layers of limestone.

1. CORNIFEROUS PERIOD (9).

Epochs. — 1. CAUDA-GALLI, or that of the Cauda-galli grit (9 *a*); 2. SCHOHARIE, or that of the Schoharie grit (9 *b*); 3. CORNIFEROUS, or that of the Onondaga and Corniferous limestones (9 *c*).

I. Rocks: kinds and distribution.

The rocks in New York, of the first two divisions of the Corniferous period, are sandstones or gritty shales. Like the beds of the preceding period, they have their largest development along the Appalachian region. But the *Cauda-galli* grit, unlike the Oriskany sandstone, lies in the *eastern* half of the State of New York, and thickens toward the Hudson, being fifty or sixty feet thick in the Helderberg Mountains. The *Schoharie* grit, named from its occurrence in Schoharie, N. Y., has nearly the same distribution; and the rock is much like the preceding, though very different in its fossils. The term *Cauda-galli* alludes to the feathery forms of a common fossil, supposed to be a sea-weed (Fig. 484).

In contrast with the above, the rock of the *Corniferous* epoch is one of the great limestones of the continent. The layers of limestone

Fig. 484.

Spirophyton Cauda-galli.

sometimes contain seams of hornstone (flint-like quartz); and to this the name *Corniferous* alludes, from the Latin *cornu*, horn, and *fero*, I bear. Much of it abounds in corals, as much so as the reef-rock of modern coral seas. The formation extends from east to west through New York, and is continued westward through Canada and much of the great Interior basin, having fully as wide a range as the Niagara limestone. It exhibits its coral-reef character grandly at the Falls of the Ohio, near Louisville, where corals are crowded together in great numbers, some standing as they grew, others lying in fragments, as they were broken and heaped up by the waves, branching forms of large and small size mingled with massive kinds, of hemispherical and other shapes. Some of the cup corals (Cyathophylloids) are six or seven inches across at top, indicating a coral animal seven or eight inches in diameter. Hemispherical compound corals occur five or six feet in diameter. The various Coral-polyps of the era had, beyond doubt, bright and varied coloring, like those of our own tropics; and the reefs were therefore an almost interminable flower-garden.

A limestone made up of similar corals occurs on Lake Memphremagog, between Vermont and Canada, showing that coral reefs flourished there also; and other localities exist to the eastward. At Cape Gaspé on the St. Lawrence Gulf, over the Gaspé limestones, there are 7,036 feet of sandstones, a portion of which, in the lower part, are supposed to be of the Corniferous period.

The formation in New York consists of two members, the *Onondaga* limestone or *lower* part, and the *Corniferous* limestone or *upper*. The hornstone occurs in the latter. This hornstone contains various microscopic fossils (Fig. 484 A), and also minute rhombic crystals, 1–500th inch across, which are probably calcite. The thickness of the two limestones in New York is in some places 350 feet.

1. The Cauda-galli grit is, in New York, a drab or brownish argillaceous sandstone, or grit, often shaly and crumbling. In New Jersey, it occurs along the northwestern boundary, and also on the eastern borders of Pennsylvania, as a dark compact gritty slate, and has a thickness in some places of 400 feet.

2 The Schoharie epoch, if represented in the rocks of the Interior basin, is so by limestone referred to the Corniferous epoch.

3. The Corniferous limestone, in New York, is dark grayish, and occasionally black; in the Interior basin, it is usually light-gray, drab, or buff.

(*a*) *Interior Continental basin.* In New York, the thickness of the limestone seldom exceeds 20 feet for the Onondaga, and 50 for the Corniferous. The limestone formation has been recognized in Ohio, along the shores of Lake Erie, in Michigan, Indiana, Illinois, Kentucky, Wisconsin, Iowa, Missouri, and other parts of the Mississippi basin: but the subdivisions above mentioned are not distinguishable. In the Michigan peninsula, the thickness is 354 feet (Winchell); in Ohio, 60 feet; in Iowa, 50 to 60 feet (Hall); in Missouri, from a few feet to 75. The upper part of the limestone in Illinois is regarded by Worthen as of the Hamilton period.

The upper layers of the rock, which are usually dark grayish in New York, are nearly black on the Niagara. In some localities west of New York, the rock is oölitic. The hornstone of the Corniferous beds is often left in rough projecting masses, where the limestone portion has been worn away by the action of water. In Missouri, siliceous and sandstone layers alternate with the limestone. These rocks outcrop also in western Canada, north of Lake Erie.

(*b.*) *Appalachian region.* — This formation extends from New York into New Jersey, where, in the northwestern part of the State, it has a thickness of 500 feet. It has not yet been distinguished among the rocks of Pennsylvania, except northwest of the Kittatinny Mountain, between the Delaware and Lehigh Rivers.

(*c.*) *Eastern Border region.* — At Owl's Head, on Lake Memphremagog, near the northern borders of Vermont, the coral-reef rock is overlaid by mica schist; and, although it is partially metamorphic, many of the specimens of fossils are tolerably perfect. Among the species, Billings has recognized *Syringopora Hisingeri* B., *Favosites basaltica* Goldf., *Diphyphyllum stramineum* B., and *Zaphrentis gigantea* Lesueur. Besides these, according to Hitchcock, *Atrypa reticularis* has been identified by Hall.

The limestone at Bernardston, Mass., containing large crinoidal stems, described on page 237, under the Lower Helderberg period, may possibly be of the Corniferous or Upper Helderberg period. At Littleton, New Hampshire, there is a similar limestone, containing corals like those of Lake Memphremagog; and conformable with it are beds of quartzyte and other rocks: the fossils are referred to the Corniferous period by Billings. Between Littleton and Bernardston extends a strip of schistose or slaty rocks, in some places calcareous, and often staurolitic, called by Hitchcock the *Coös Group*, which are either Lower or Upper Helderberg.

Between northern Vermont and Cape Gaspé, there are many localities of Devonian fossils. One locality, given by Logan, is on the Chaudière River, where there occur, besides *Favosites Gothlandica* and *F. basaltica*, the species *Syringopora Hisingeri*, *Diphyphyllum arundinaceum* B., a small *Productus* resembling a Corniferous species, a *Zaphrentis*, *Spirifer duodenarius* H., *S. gregarius* Clapp, *S. acuminatus* H., a *Cyrtina* like *C. rostrata* H., etc. Other localities occur at Dudswell and on Famine River. At Cape Gaspé, the upper part of the 2,000 feet of limestone contains Oriskany fossils (p. 243), but none indicative of the Corniferous period.

Economical Products.

The limestone of this period in some places abounds in mineral oil. The oil wells of Enniskillen, Western Canada, are traced to this rock by Hunt; large areas are there covered with the inspissated bitumen. At Rainham, Canada, on Lake Erie, shells of *Pentamerus aratus* are sometimes filled with the oil: and, in other localities, corals of the genera *Heliophyllum* and *Favosites* have their cells full, in some layers of the lime-

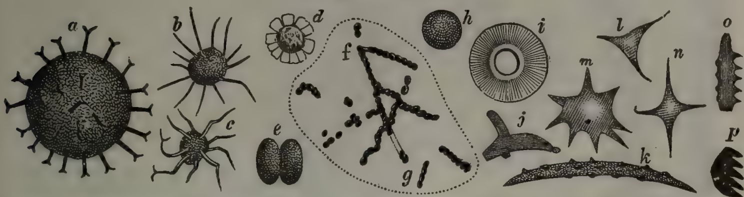
stone, while empty in other layers. At Terre Haute, Indiana, a well 1,900 feet deep, into the Corniferous limestone, yields two barrels of oil a day, and a second well, 1,775 feet, but to the same level (the first 150 feet through gravel), 25 barrels.

II. Life.

1. *Plants.*

Among Seaweeds, the most remarkable is the spirally convoluted *Spirophyton cauda-galli*, figured on page 255.

Fig. 484 A.



MICROSCOPIC ORGANISMS IN HORNSTONE. — Figs. *a–i*, Protophytes; *j–n*, Spicula of Sponges; *o*, *p*, fragments of dental apparatus of Gasteropods.

The hornstone in the Corniferous limestone, as shown by Dr. M. C. White, is full of miscroscopic plants, or protophytes, from 1-500th to 1-5000th of an inch in diameter; and with them are sponge-spicules and teeth of mollusks. Some of them are represented in Fig. 484 A: *a* to *e* are *Xanthidia*, spore-capsules of Desmids (p. 135), *f*, *g*, conferva-like filaments, made of a series of cells; *i*, a Diatom, one of the silica-secreting protophytes; while *j*, *k*, *l*, *m*, *n* represent siliceous spicula of sponges, and *o*, *p*, teeth of mollusks. The mass of the hornstone was probably made out of siliceous diatoms, sponge-spicules, and perhaps also polycystines.

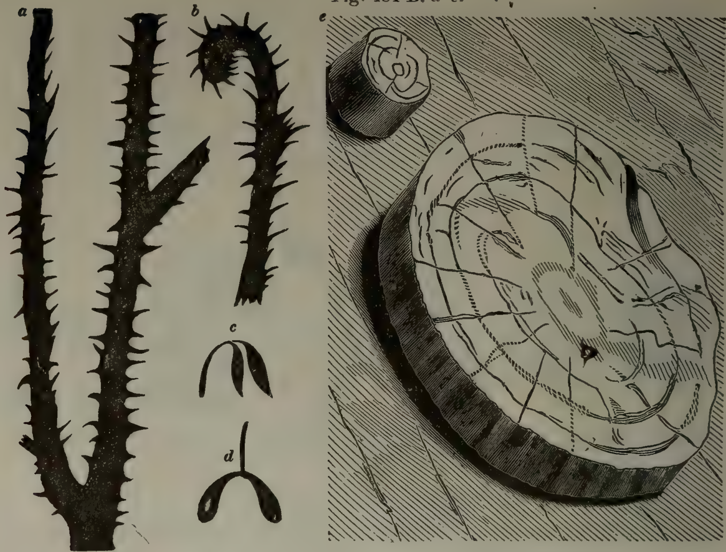
The terrestial plants are, — *first*, under the division of Acrogens, or the higher Cryptogams, species of *Lycopods* (or Ground Pines) and *Ferns*; *second*, under Gymnosperms, or the lower division of Phenogams, *Conifers*. In the lower sandstones of Gaspé occur remains of the Lycopods and Conifers, and in the Corniferous limestone of Ohio, the Ferns.

1. *Lycopods.* — The Lycopods include species of *Psilophyton*, like those of the Oriskany period: portions of the plant, with its dried leaves, are shown in Figs. 484 B, *a*, *b*, and its fructification in *c*, *d*.

The species differ from the common Ground Pine in having the leaves nearly wanting, on the flowering stems, and also in having the axis, or a cylinder around the centre, made up of scalariform vessels, and the spore-cases (fruit) usually in pairs on short pedicels; and in these respects they resemble the plants of the genus of Lycopods

called *Psilotum*, whence the name *Psilophyton*. The species of the Corniferous era thus far described were from one to three feet high.

Fig. 484 B. *a–e*.



Figs. *a*, *b*, *c*, *d*, Psilophyton princeps; *e* Prototaxites Logani (× ⅛).

2. *Conifers.* — The Conifers are species of the earliest known genus of the family *Prototaxites;* and portions of two branches are shown, reduced, in Fig. 484 B, *e* (from Dawson); the larger was 18 inches across. Another was three feet in diameter, indicating that there were forests of these Devonian yews.

3. *Ferns.* — Newberry has found the remains of *Tree-ferns* in the Corniferous of Ohio, showing that these also were among the trees of the forests. A portion of one is represented in Fig. 484 C.

Fig. 484 C.

Caulopteris antiqua.

The projecting parts over the trunk are the bases of the fallen fronds, just such as occur over the exterior of some modern tree-ferns. In the plate on page 322, a modern tree-fern stands to the left of the middle, and the plants below are small ferns.

Fig. 484 B, *a*, *Psilophyton princeps;* *b*, the growing extremity of a branch, incurved or circinnate; *c*, *d*, fructification. Fig. 484 B, *e*, *Prototaxites Logani*, one eighth the natural size. The species of Tree-ferns found in the Ohio limestone are *Caulopteris antiqua* Newb. (Fig. 484 C), *Caulopteris peregrina* Newb. (*Protopteris peregrina* Dn).

Meek has found, in the Corniferous beds of Ohio, globular particles, about a twentieth

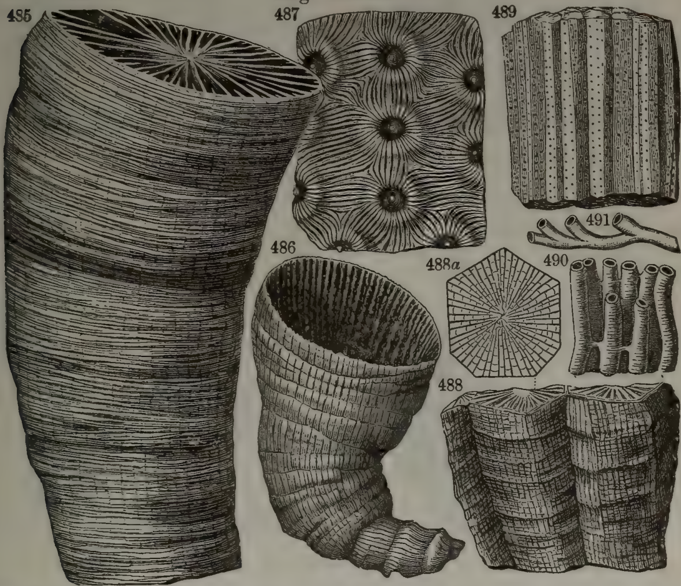
of an inch in diameter, marked with eight spiral ridges, which he regards as seeds of a *Chara.* These frequently occur also in the cellular chert at the Falls of the Ohio.

2. *Animals.*

The Corniferous period was, as has been stated, eminently the *coral-reef period of Paleozoic time.*

1. **Invertebrates.** — The existence of Sponges is indicated by the

Figs. 485–491.



POLYPS. — Fig. 485, Zaphrentis gigantea; 486, Z. Rafinesquii; 487, Phillipsastrea Verneuili; 488, 488 *a*, Cyathophyllum rugosum; 489, Favosites Goldfussi; 490, Syringopora Maclurii; 491, Aulopora cornuta.

presence of their siliceous spicula in the hornstone, two slender forms of which are shown in Figs. 484 A, *j*, *k*, page 257, and others in *l*, *m*, *n*.

Fig. 492.

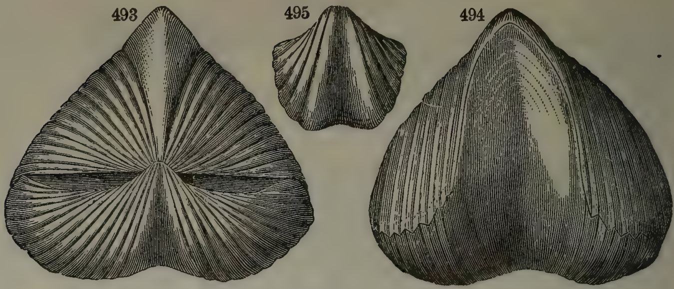
Nucleocrinus Verneuili.

Figures 485 to 491 represent some of the corals; 486 shows well the radiated cup-shaped termination to which the name *Cyathophylloid* corals (from κύαθος, *cup*, and φύλλον, *leaf*) refers; 485 has both extremities broken off, but exhibits the interior radiation; 489 is a portion of a common species of *Favosites* (honey-comb coral, named from *favus*, *honey-comb*), a kind that sometimes occurs in hemispheres five feet in diameter; 487 is part of the surface of a common massive coral.

Among Echinoderms, the most interesting are species of the group of *Blastids*, or Bud-Crinoids, having no proper arms, one of which is

represented in Fig. 492. Though ovoidal in form, it is related to the

Figs. 493–495.



BRACHIOPODS. — Figs. 493, 494, Spirifer acuminatus; 495, Sp. gregarius.

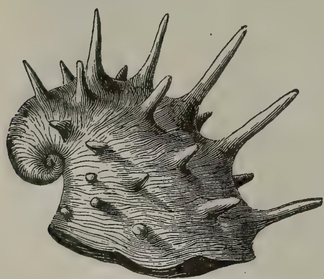
pentagonal *Pentremites*, a kind that was particularly abundant in the Lower Carboniferous (Fig. 580, p. 298).

Figs. 496–497.

CONCHIFERS. — Fig. 496, Lucina (?) proavia; 497, Conocardium trigonale.

Brachiopods were very numerous; and figures 493 to 495 represent common species. The genus *Productus* here had its first species — a genus that was very numerously represented in the Carboniferous formation. Its earliest species are half an inch broad, and some of the later three or four inches. The character of the shell is illustrated in Figs. 238, 239, *a*, page 173.

Fig. 498.



Platyceras dumosum.

There were also various other kinds of Mollusks. Among them occur spinous species of the genus *Platyceras*, one of which is represented in Fig. 498. In the hornstone was found (by Dr. White) the dental apparatus of a Gasteropod, represented in Fig. 484 A *o*. [*p* is another form, in horn-

stone of the Black River limestone (p. 194), from Watertown, N. Y., which affords also Desmids and spicules of Sponges.]

Characteristic Species.

1. Radiates. — (*a.*) *Polyps.* — Fig. 485, *Zaphrentis gigantea;* Fig. 486, *Zaph. Rafinesquii* E. & H., from the Falls of the Ohio. Another Cyathophylloid coral, of the genus *Chonophyllum* (*C. magnificum* B.), has a diameter at top of six or seven inches; it is from Walpole, Canada West. Fig. 487, *Phillipsastrea Verneuili* E. & H.; Fig. 488, *Cyathophyllum rugosum*, a fragment from a large mass from the Falls of the Ohio; 488 *a*, section of a cell; Fig. 489, *Favosites Goldfussi* D'Orb., from the Falls of the Ohio, a fragment of a large specimen; Fig. 490, *Syringopora Maclurii* B., from Canada West, a coral consisting of a cluster of small tubular cells; Fig. 491, *Aulopora cornuta* B., from Canada.

(*b.*) *Acalephs.* — No species are known, unless some of the Corals belong here.

(*c.*) *Echinoderms.* — There are many species of Crinoids, and the large, smooth stems of some of them are half an inch to an inch in diameter. Of the *Nucleocrini* (also called *Olivanites*), Fig 492 represents the *N. Verneuili* L. & C. The name *Nucleocrinus* of Conrad antedates *Olivanites* Troost, and *Elæacrinus* Roemer.

2. Mollusks. — (*a.*) *Brachiopods.* — Figs. 493 and 494, *Spirifer acuminatus* Con. (*S. cultrijugatus* Roemer), from New York and the West. Fig. 495, *Spirifer gregarius* Clapp, very common in Indiana and Kentucky, at the Falls of the Ohio, and at Middleton, Canada (Billings). Also, *Pentamerella arata* H., *Chonetes hemisphærica* H., *Atrypa reticularis, A. impressa* H., *A. spinosa* H. (*A. aspera*), *Amphigenia elongata* (formerly *Pentamerus elongatus* Vanuxem, and *Stricklandinia elongata* Billings), *Rhynchonella venustula* Hall (*Atrypa cuboides* of Sowerby, also Vanuxem), found in Tennessee. Two small species of *Productus* have been collected by Billings in Canada, and one by Jewett in the New York Corniferous.

(*b.*) *Lamellibranchs.* — Fig. 496, *Lucina* (?) *proavia* Goldf., also occurring in Europe; Fig. 497, *Conocardium trigonale*, of both New York and the West. The first known species of *Solenomya* (Meek), and also of *Orthonema*, another Carboniferous genus.

(*c.*) *Pteropods, Gasteropods,* and *Cephalopods.* — Pteropods are represented by the *Tentaculites scalaris* Schlot. There are also several species of Gasteropods. Fig. 498 is the *Platyceras dumosum* Con., of the Corniferous in New York.

A few Orthocerata occur in the beds. The *Cyrtoceras undulatum*, a large shell coiled in a plane, is supposed, as the name implies, to be related to the Cephalopods.

3. Articulates. — Trilobites are the only Articulates known. The most common species are the *Dalmanites* (*Odontocephalus*) *selenurus* H., having a two-pointed tail; and the *Proëtus* (*Calymene*) *crassimarginatus* H., having the posterior margin of the body (the pygidium) thickened and rounded. There are also *Phacops bufo* H., and some other species.

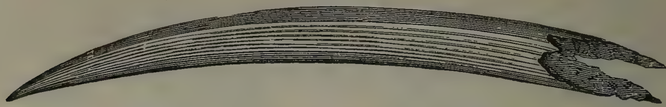
The following species continue on into the Hamilton: *Orthis Vanuxemi* H.? *Streptorhynchus Chemungensis* H., *Strophodonta* (*Strophomena*) *demissa* H., *S. perplana* H. (= S. crenistria H.), *Spirifer fimbriatus* Con. (found also in the Oriskany, *Atrypa impressa* H. (= var. of *A. reticularis*), *Phacops bufo.*

4. Vertebrates. — The remains of Vertebrates, under the form of Fishes, appear first, in America, according to present knowledge, in the rocks of the Corniferous period. The subdivisions of fishes represented are the same that have been distinguished in the foreign Upper Silurian. They are the following, —

1. The Shark-tribe or Selachians (so named from σέλαχος, a cartilaginous fish), the bones being cartilaginous or mostly so. In this division, the gill-openings, as shown in Fig. 502, have no operculum.

Fig. 499 represents a spine from the fin of a Shark (from Ontario County, N. Y.), which was originally at least ten inches long. Figures 502, 504, illustrate the positions of such spines.[1]

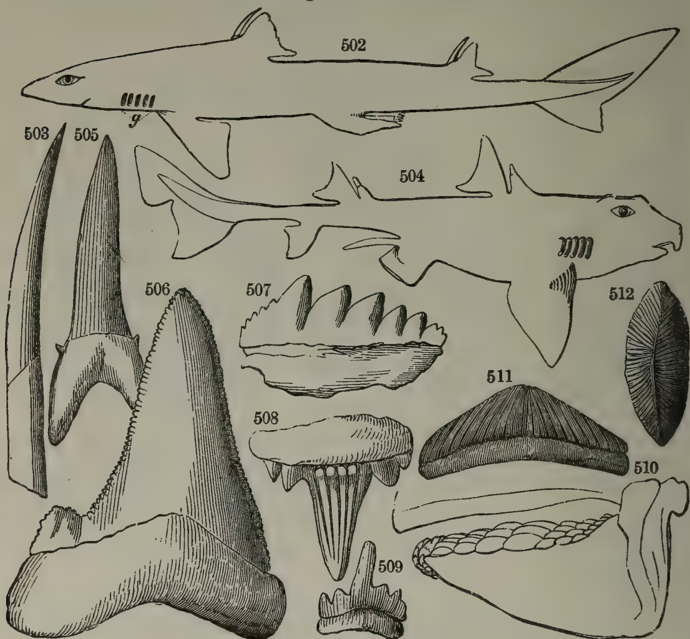
Fig. 499.



Fin-spine of a Shark, Machæracanthus sulcatus ($\times\frac{2}{3}$).

Other remains of sharks are the teeth or bones of the mouth. The masticating apparatus in some of the ancient sharks, as in the

Figs. 502–512.



SELACHIANS. — Fig. 502, Spinax Blainvillii ($\times\frac{1}{8}$); 503, Spine of anterior dorsal fin, natural size; 504, Cestracion Philippi ($\times\frac{1}{8}$); 505, Tooth of Lamna elegans; 506, id. Carcharodon angustidens; 507, id. Notidanus primigenius; 508, id. Hybodus minor; 509, id. Hyb. plicatilis; 510 Mouth of Cestracion, showing pavement-teeth of lower jaw; 511, Tooth of Acrodus minimus; 512, id. Acrodus nobilis.

modern *Cestracion* of Australia (Fig. 504, reduced), was a pavement of bony pieces; Fig. 510 shows the pavement of the lower jaw of

[1] In several genera of Selachians, the dorsal fin is armed at its anterior margin with a large spine. In the genus *Spinax* (Fig. 502, reduced), there are such spines, one to each dorsal fin; Fig. 503 represents one of natural size for a fish (*Spinax*) about $2\frac{1}{4}$ feet long. — Such spines exist also in the *Cestracionts* (Fig. 504), the *Hybodonts*, and the

the *Cestracion*. The Corniferous of Ohio and Indiana has afforded such bony pieces, showing that Cestraciont sharks were among the first. For further illustration of these species, Figs. 511, 512 are introduced, giving the forms of these pieces in Cestraciont sharks of a later age. The Cestracionts had teeth of nearly the usual form, at the front margin of the jaw.

Besides these Cestracionts, there were *Hybodont* sharks, having teeth much like those of the more modern kinds of sharks. These teeth occur in the American Corniferous, and have been described and figured by Newberry (Ohio Geological Survey). Figs. 508, 509 represent those of early Mesozoic Hybodonts, while Figs. 505, 506, 507 give the forms of the teeth in other sharks of a still later era.

2. *Ganoids*, having the body covered with shining bony scales or plates, as in the Gar-pike of existing waters, and hence named *Ganoid* by Agassiz, from γάνος, *shining*. The bones of the early species were cartilaginous. The scales of the ordinary Ganoids are often rhombic in form (Fig. 513), and are fitted to one another like tiles; Figs. 513, 514, 515, 515 *a* illustrate some of their forms and modes of junction, though not drawn from Corniferous species. Fig. 570, p. 286, is a foreign Devonian Ganoid, having scales of this form (Fig. 570 *a*). Others have the bony scales nearly circular, and set on more like shingles, as in the genus *Holoptychius*. A foreign Devonian species is represented in Fig. 569, p. 286. The head of a large *Ganoid*, found in Indiana and Ohio, which Newberry supposes to have had no teeth, is represented, reduced, in Fig. 522. Remains of a still larger species, called *Onychodus* by Newberry, occur in the Ohio Corniferous, which had scales and teeth much like the *Holoptychius*. It had jaws a foot to a foot and a half long, with teeth two inches or more long in the lower jaw (Fig. 523), and three-fourths of an inch in the upper. Some of them probably had a length of twelve or fifteen feet.

Figs. 522, 523.

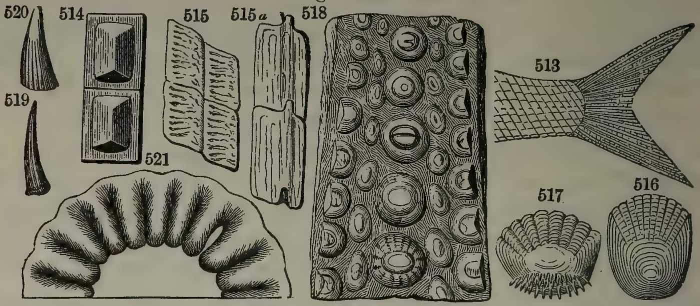
Fig. 522, Head of Macropetalichthys Sullivanti (×¼); 523, tooth of lower jaw of Onychodus.

In another type of Ganoid, a bony plate covers the head, and this

Chimæroids. In these Squaloid groups, the spine is usually laterally compressed, and if denticulate it is so along the posterior margin. In *Trygon* and some other genera among the Rays, there is a similar spine; but it is flattened in a direction transverse to the body, and has both outer edges denticulate, when either is at all so. These spines in some ancient fishes were two feet or more in length (see Fig. 612, p. 308.) In a living *Cestracion*, 23 inches long, it is $1\frac{1}{2}$ in length.

is the most ancient kind of fish known. From the name of the genus *Cephalaspis* (signifying *shield-like head*), the group is called *Cephalaspids.* Two of these head-shields are figured among Upper Silurian fish-remains, on page 246, and the form of an entire British Devonian specimen, in Fig. 568, on page 286. The only species of the kind in the American Corniferous is a *Cephalaspis,* from Gaspé, on the Gulf of St. Lawrence.

Figs. 513–521.



Ganoids (excepting 516, 517). — Fig. 513, Tail of Thrissops (×½); 514, Scales of Cheirolepis Traillii (×12); 515, id. Palæoniscus lepidurus (× 6); 515 *a*, under-view of same; 516, Scale of a Cycloid; 517, id. of a Ctenoid; 518, part of pavement-teeth of Gyrodus umbilicus; 519, Tooth of Lepidosteus; 520, id. of a Cricodus; 521, Section of tooth of Lepidosteus osseus.

The teeth in these Ganoids are often large and conical. Two of them are represented in Figs. 519, 520; they are furrowed vertically, and have an internal labyrinthine structure, as represented (in one of its simpler varieties), in Fig. 521, a view of a transverse section enlarged.

The tails of the ancient Ganoids were *vertebrated,* that is, the vertebral column extended nearly or quite to the extremity; generally following the course of the upper lobe of the caudal fin, as in Fig 570, p. 286, and Fig. 696, p. 371, but sometimes terminating at the extremity of the middle of the tail (p. 336). In modern Ganoids, on the contrary, as in ordinary fishes, the vertebral column stops at the commencement of the caudal fin, as in Fig. 513. Five genera of living Ganoids (*Lepidosteus* or Gar-pike, *Amia, Accipenser* or Sturgeon, *Spatularia,* and *Scaphirhynchus*), belong to North America, and the other two known are African.

3. *Placoderms,* fishes having the body partly or wholly covered by bony plates, turtle-like, and named from πλάξ, *plate,* and δέρμα, *skin,* with which the Cephalaspids are often united. It is questioned whether they were more nearly related to the sharks or to the Ganoids. Two foreign species of Placoderms are represented, reduced, in Figs. 566, 567, p. 285. Newberry has described a dorsal plate of a related fish, found in the Ohio Corniferous, which has a length and breadth of eight inches.

The *Osseous fishes* or *Teliosts*, which include nearly all modern kinds, except the Sharks and Rays, and have usually membranous scales (like Figs. 516, 517, the former a "*Cycloid*" scale and the latter a "*Ctenoid*"), are not known among fossils before the Middle Mesozoic.

The lowest division of modern fishes includes a few very small kinds, like the *Amphioxus*, which are scale-less, fin-less, brain-less, without special organs of sense beyond feelers around the mouth, and with the skeleton membranous, and the heart rudimentary. These lowest of Vertebrates, inferior even to the higher Radiates, would naturally be looked for as precursors of the Selachians and Ganoids; but no remains of them have been found. Had such species existed, however, they could scarcely have left remains, as they have no hard parts.

III. General Observations.

Geography. — In the first epoch of this period, that of the Cauda-galli grit, the beds were, as a body, more easterly in position over New York than those of the preceding period. In the Schoharie epoch, they were still farther to the east than the Cauda-galli grit; at the same time, they continue to be sandstones. But with the next epoch there was a change. The continent, from eastern New York westward, became to a large extent covered with coral-growing seas. The wide distribution of the rocks proves the vast area of those coral seas. It also teaches that they were shallow seas; for so large corals would form limestones only where they were within the reach of the waves.

The presence of the hornstone, through many layers of the limestone, indicates that, over the bottom, where mollusks and other species were living and making the material for the limestones, there were often also Sponges and Diatoms or Polycystines, making microscopic siliceous shells and spicules; so that, while the calcareous sands of the former were solidifying into limestone, the microscopic grains of silica became aggregated here and there into siliceous concretions or masses of hornstone.

Climate. — The question of the occurrence of rocks of this period in the Arctic region is not yet decided. It is probable that they exist there, on North Somerset and elsewhere, judging from the fossil corals and Brachiopods.[1] Among the former, besides the *Favosites Gothlandica* (Upper Silurian in Europe), there are *Heliolites porosa* and *Cyathophyllum helianthoides*, Devonian species common to both Europe and America.

This identity of species between Arctic lands and Europe and

[1] *Am. Jour. Sci.*, II. xxvi. 120.

America, just illustrated, favors an approximate identity of climate: there is no sufficient evidence of any cold Arctic, or even of any wide diversity of zones.

2. HAMILTON PERIOD. (10.)

Epochs. — 1. MARCELLUS, or that of the Marcellus shale (10 *a*); 2. HAMILTON, or that of the Hamilton beds (10 *b*) ; 3. GENESEE, or that of the Genesee shale (10 *c*).

I. Rocks: kinds and distribution.

The rocks in New York and along the Appalachians are either shales or sandstones, with some thin limestone beds. Shales especially abound in New York.

The *Marcellus shale* (10 *a*) is for the most part a soft, argillaceous rock; the lower part is black with carbonaceous matter, and contains traces of coal or bitumen, so as sometimes to afford flame in the fire. The *Hamilton beds* (10 *b*) in New York (so named from Hamilton, Madison County, N. Y.) consist of shales and flags, with some thin limestone beds. The excellent flagging-stone in common use in New York and some adjoining States, often called North-River flags, comes from a thin layer in the Hamilton. The *Genesee shale* (10 *c*) is a blackish bituminous shaly rock, overlying the Hamilton.

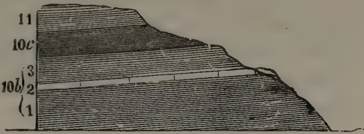
The Hamilton formation spreads across the State of New York, having its northern limit along a line running eastward from Lake Erie. The greatest thickness — about 1,200 feet — is found east of the centre of the State. It extends southwest, into Pennsylvania and Virginia; also westward, as a thin rock, mainly of limestone, through parts of Ohio, Michigan, and Illinois (at Rock Island, etc.), to Iowa (New Buffalo, etc.) and Missouri. Following this limestone, in Ohio, Indiana, and Illinois, there is what is called the *Black shale* (or *Black slate*), corresponding apparently to the *Genesee shale;* it occurs also in Kentucky and Tennessee, but, although so wide spread, does not exceed 350 feet in thickness, and is usually about 100 feet.

Hamilton beds occur also in the valley of the Mackenzie River, between Clear Water River and the Arctic Ocean, some of the species of fossils being identical with those of the United States and Canada; and, as stated by Meek, Devonian rocks are probably continuous, or nearly so, from western Illinois northwesterly to the Arctic Ocean, a distance of 2,500 miles.

In the *Eastern-border region*, the Hamilton beds are chiefly sandstones, and are confined to regions near the sea-border. They occur in Maine and New Brunswick, near the boundary between these States, and beyond up the New Brunswick coast; also at Gaspé, on the Gulf of St. Lawrence.

(*a.*) *Interior-Continental basin.* — The *Hamilton beds* consist of shales, separated into two parts by a thin layer of *Encrinal* limestone, and in many places overlaid by a thin limestone stratum called the *Tully limestone.* In the annexed section, from the coast of Lake Erie (as given by Hall), the Hamilton beds, 10 *b*, include (1) blue shale, (2) Encrinal limestone, (3) Upper or Moscow shale: the Tully limestone is wanting. Above lie (10 *c*) the Genesee slate, and (11) a part of the Portage group of the next (Chemung) period. In the lower part of the Marcellus shale (the rock of the first epoch) in New York, there are also layers of concretions of impure limestone, and these abound most in fossils; but the fossils of the shale are generally small.

Fig. 524.



Section of Hamilton Beds, Lake Erie.

The flagging-stone of the Hamilton is quarried near Kingston, Saugerties, Coxsackie, and elsewhere on the Hudson, in Ulster, Greene, and Albany counties, N. Y. The bed is but a few feet thick. It breaks into very even slabs of great size. It is almost without fossils, but is penetrated in many parts by the filling of a slender worm-hole; and its surfaces are often marked with tracks of Mollusks. The Genesee slate overlies the Tully limestone, when this is present. It is not recognized in the eastern part of the State of New York. The limestone stratum of Illinois, referred to the Marcellus and Hamilton epochs, is not over 120 feet in thickness.

The Marcellus shale rarely exceeds in thickness 50 feet. The Hamilton strata are 1,000 feet thick in central New York, but not half this along Lake Erie. They are also comparatively thin and more sandy on the east, in the Helderberg Mountains. They are well exposed along the valleys of Seneca and Cayuga Lakes. The Genesee shale is 150 feet thick near Seneca Lake: it thins westward, and is not over 25 feet on Lake Erie.

The Black shale is 350 feet in Ohio, and 10 to 60 feet in Illinois. In Tennessee, west of the Cumberland table-land, it has at top a thin layer of small concretions, and below it, a bed of fetid limestone; it outcrops on the slopes around the central basin of the State. As no other rock intervenes between the Corniferous and Carboniferous, this Black shale has been suspected to be Chemung, but without any satisfactory evidence from fossils. A thin band of concretions at the top of this bed, in central Kentucky, contains many remains of fishes, and also crustaceans, of the genera *Colpocaris*, *Solenocaris*, *Archæocaris*, the two former closely allied to *Ceratiocaris.*

In Missouri, the Hamilton formation consists of about 50 feet of shale, with some beds of limestone. In Iowa, there are 200 feet of shales and limestone, and no other Devonian rocks.

(*b.*) *Appalachian region.* — In Pennsylvania, H. D. Rogers makes three divisions of the Hamilton formation, a lower of black shales, which is 250 feet thick in Huntingdon, a middle of variegated shales and flags, 600 feet thick at the same place, and an upper black shale of 300 feet. In East Tennessee, the thickness is 100 feet. (Safford.)

The thickness of the Hamilton formation east of central New York shows that this region was at this time, as in the Oriskany period, on the northern border or limits of the Southern Appalachian region.

(*c.*) In the *Eastern-border* region, at Gaspé, the 6,000 feet of sandstones, above the 1,100 referred to the Corniferous period, are believed to be for the most part of Hamilton age. St. John's, in New Brunswick, is a noted locality of fossil plants of this era.

Ripple-marks. — The rocks of this formation, especially the Hamilton beds, are remarkable for the abundance of *ripple-marks* on the layers. The flagging-stone is often covered with ripple-marks and wave-lines. The *joints* intersecting the strata are often of great extent and regularity. They have been referred to on page 88; and

a sketch is there given, representing a scene on Cayuga Lake. The rock at the place is the Moscow shale.

Economical Products.

The Hamilton beds afford the best flagging-stone of the country.

The *Black shale*, or Genesee shale, is remarkable as an oil-yielding rock. This is true in New York and all through the West, wherever it has much thickness. In Tennessee, the shale sometimes yields fifteen to twenty per cent. of mineral oil and tars. In Ohio, where it is 350 feet thick, it contains, according to Newberry, ten per cent. of combustible matter, and is therefore equivalent to a coal seam 40 feet thick.

This oil, obtained from the rock, is not present in it as oil, for no solvents will separate it: it is produced by the heat of distillation out of the carbonaceous substances present. This shale has been regarded as the main original source of the oils in the oil region of Ohio and Western Pennsylvania; but there is reason to believe that part at least of the supply in these regions has come from the Corniferous limestone below it.

In the oil regions, gas is often given out from the borings, and is used for lighting and warming houses, and various other economical purposes.

The same rock often contains much pyrite, and might be used for making copperas and alum. Efflorescences of both of these substances are common in sheltered places. It is a source also of numerous sulphur springs.

II. Life.

1. *Plants.*

The carbonaceous material of the black Marcellus shale is of organic origin; but whether due to sea-weeds or to land-plants, or partly to fishes or other animals, has not been ascertained.

In the Hamilton beds, the evidences of verdure over the land are abundant. The remains show that there were trees, as well as smaller plants; that there were forests of moderate growth, and great jungles over wide-spread marshes.

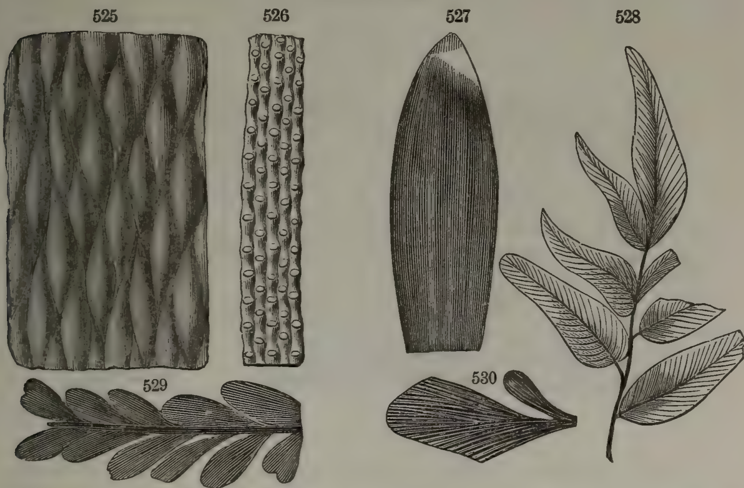
These terrestrial plants include *Lycopods*, *Ferns*, and *Equiseta*, the three orders of Acrogens, or higher Cryptogams, and also *Charæ*, but no true Mosses; and with these there were *Gymnosperms*, or the lower Phenogams.

1. *Lycopods.* — The Lycopods of the Hamilton were of three types; (1) the *Psilophyta*, or the slender forms, which were the earliest repre-

sentatives of the order (pp. 242, 245), and which in the Hamilton are the least common kind; (2) the *Lepidodendrids*, having the scars which mark the places of the leaves in alternate or quincunx order (Fig. 525); and (3) the *Sigillarids*, which have the scars in vertical series (Fig. 526).

The *Lepidodendrids* were in part trees, and they much resembled in habit modern Spruces and Pines, the leaves having been long and narrow and crowded over the branches. A portion of the scarred exterior of a branch, from New York, is represented in Fig. 525. Good examples of such scars are to be found on a small branch of a common spruce. Fig. 527 represents a broad leaf of the genus *Cordaites*, which belonged to a Lycopod, according to some authorities, but more probably to a Conifer (p. 329).

Figs. 525–530.



ACROGENS. — Fig. 525, Lepidodendron primævum; 526 Sigillaria Hallii; 527, Cordaites Robbii; 528, Neuropteris polymorpha; 529, 530, Cyclopteris Jacksoni.

The *Sigillarids* grew up as stout trunks, some of them thirty or more feet high, with rarely a branch, and with long linear leaves (or fronds) about the summit. Fig. 526 represents a portion of a very small species, from New York, showing the vertical series of scars. Trunks of *Sigillaria* have been found having a base of spreading branches looking like roots; but the supposed roots, according to Lesquereux, are underwater stems. These stems have round, scattered, pit-like depressions over the surface, where the underwater leaves were attached, and are called *Stigmariæ*, from the Latin *stigma, a dot*. Part of a stem of a Carboniferous *Stigmaria* is represented in Fig. 624,

p. 324). The modern *Isoëtes* (referred to the Lycopods by many Botanists) are regarded by the best authorities as the nearest allies of the ancient Sigillarids; they are from an inch to two feet in height, and have nearly linear leaves, but no trunk; if they were capable of growing upward, like many other Acrogens, and producing a trunk, the plant with its long leaves would much resemble the Sigillarids.

2. *Ferns.* — Forty or more species of Ferns have been described from beds of the Hamilton period, the most of them from those of St. John, New Brunswick. One species, a *Neuropteris*, is represented in Fig. 528; part of a frond of another, a *Cyclopteris*, in Fig. 529, and a single leaflet in Fig. 530. Large trunks of tree-ferns (peculiar in their very large scars), have been found in the New York and Ohio Hamilton beds.

3. *Equiseta* or *Horse-tails.* — This tribe of plants was represented by plants called *Calamites* (from *calamus*, a *reed*), in allusion to their

Figs. 531, 532.

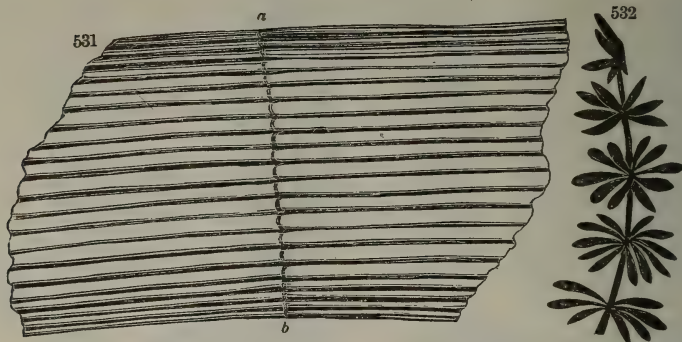


Fig. 531, Calamites Transitionis; 532, Asterophyllites latifolia.

reed-like or rush-like aspect. Fig. 531 represents a portion of a stem (in horizontal position) flattened out. Like the modern *Equisetum*, the stem was jointed (at *ab* in Fig. 531), and separated easily at the joints, and the surface was finely furrowed. The modern Equiseta have hollow stems. Fig. 532 represents a species of *Asterophyllites*, — the name signifying *star-leaf* — a plant of undetermined relations.

4. *Gymnosperms.* — These plants belong to the order of *Conifers*, which includes plants related to the Yew, Pine, Spruce, etc. Lesquereux mentions the occurrence of trunks of Conifers a foot in diameter, in the Black shale of the Hamilton; and others, as large or larger, are described by Dawson from the New Brunswick beds.

For the descriptions of American Devonian plants, science is largely indebted to Dr. J. W. Dawson (Quart. J. G. Soc., xv. 483, xviii. 296, xix. 458, xxvii. 270; also his

Acadian Geology, 2d ed., 1868; also On the Fossil Plants of the Devonian, etc., published by the Geol. Survey of Canada in 1871). Some species have been described also by C. F. Hartt (Bailey's New Brunswick Geol. Rep., 1865), and by Newberry and Lesquereux.

Lepidodendron primævum Rogers (Fig. 525) is from Huntingdon, Pa ; the small *Sigillaria Hallii* D., Fig. 526, from Otsego County, New York. Species of *Psilophyton* have been reported, by Dawson, from the Hamilton and Chemung of New York and Ohio, as well as from Gaspé and from Perry, Maine. *Lepidodendron Gaspianum* Dn., a Gaspé species, occurs also in the Upper Hamilton and Catskill beds of New York and New Brunswick. *Psaronius Erianus* Dn. and *Caulopteris Lockwoodi* Dn. are tree-ferns from the Hamilton of Madison County, New York. *Arthrostigma gracile* Dn. is the name of a Gaspé plant, much resembling *Psilophyton*. *Psilophyton*, *Prototaxites*, and *Arthrostigma* are regarded by Dawson as forms becoming nearly extinct in the Middle Devonian.

The following are some of the St. John species; those that occur also at Gaspé are marked with an asterisk, and those also in New York or the West, with a dagger.

Psilophyton princeps Dn.*† (Fig. 484 B, p. 258), *Lepidodendron Gaspianum* Dn., *Sigillaria palpebra* Dn., *Stigmaria perlata* Dn., *Cordaites Robbii*† (Fig. 527), *Cyclopteris Jacksoni* (Figs. 529, 530) *Neuropteris polymorpha* Dn. (Fig. 528), *N. Dawsoni* Hartt. (leaflet over six inches long), *Sphenopteris Hitchcockiana* Dn., *S. Hœninghausi* Brngt., *S. Harttii* Dn., *Callipteris pilosa* Dn., *Hymenophyll tes Gersdorffii* Göpp., *H. obtusilobus* Göpp., *Alethopteris discrepans* Dn., *Pecopteris preciosa* Hartt., species of *Trichomanites*, *Calamites transitionis* Göpp. (Fig. 531), *C. cannæformis* Brngt.; *Asterophyllites acicularis* Dn., *A. latifolia* Dn. (Fig. 532), *Sphenophyllum antiquum* Dn.; *Dadoxylon* (*Araucarites*) *Ouangondianum* Dn., besides fruits of the genera *Cardiocarpum* and *Trigonocarpum*.

A kind of fossil wood from Eighteen-mile Creek, New York, named *Syringoxylon mirabile* by Dawson, and announced by him as having the structure of an Angiosperm, is made a Conifer, of the genus *Araucaroxylon*, by Lesquereux.

The figure of *Cyclopteris Jacksoni*, 529, is from a Gaspé specimen (Dawson). A New Brunswick specimen, figured by Dawson, is ten inches long, and only part of a frond; it has a dozen pinnules (branchlets) like Fig. 529, either side of the stem; and Fig. 530, showing the neuration, is taken from it. The genus (sometimes called also *Nœggerathia*, and by Schimper *Palæopteris*) is prominently Devonian, it disappearing in the early Carboniferous. Other species are figured on pages 277, 279. These early ferns, with the species of *Callipteris*, and probably those of *Neuropteris* and *Sphenopteris*, kinds that commence during or before the middle Devonian, are probably, as suggested to the author by D. C. Eaton, related to the modern *Botrychium* and *Ophioglossum*, genera having, as Hooker states, the fruit nearly like that of Lycopods, and differing from ordinary ferns also, in the leaf not being rolled into a coil when first developed, and therefore not uncoiling as it opens. This would make them intermediate between the Lycopods, the earliest known form of terrestrial plants, and the true Ferns.

2. *Animals.*

The animal remains of the Marcellus are comparatively few, and, excepting the Goniatites, generally small: their small number corresponds with the fact that the rock is a fine shale. In the Hamilton beds, which are coarser, and often resemble a consolidated mud-bed, fossils are much more numerous. With the Genesee slate, there is a return to the fineness of the Marcellus, and also in part to some of the same species of shells. The *Black shale* contains but few fossils; among them, *Lingula subspatulata* M. & W., a *Discina* and a *Chonetes*, with remains of Fishes and Crustaceans.

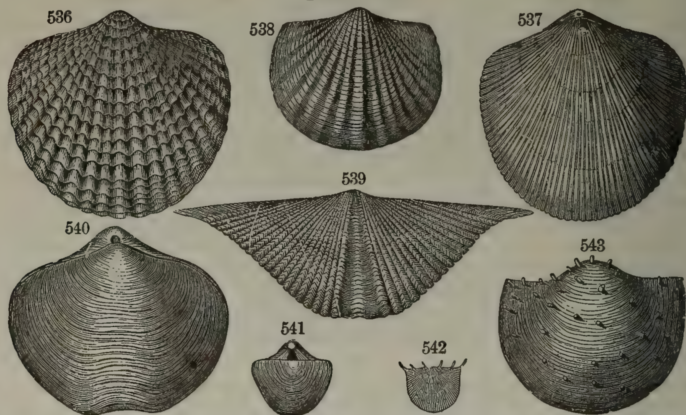
The preceding period had abounded in corals, and hence in limestones; in the Hamilton, when the condition was unfavorable for Coral reefs, over New York and to the south, there were still some large species of corals and Crinoids; but the predominant fossils were Brachiopods and Lamellibranchs — species that live on muddy bottoms. There were many broad-winged Spirifers, among which the *Sp. mucronatus* (Fig. 539) was very common. The limestone layers mark an occasional change to clearer waters, when crinoids and corals had a chance to flourish.

Fig. 535.

Heliophyllum Halli.

Brachiopods continued to be the most common of fossils. Figures 536 to 543 represent the most common kinds.

Figs. 536–543.



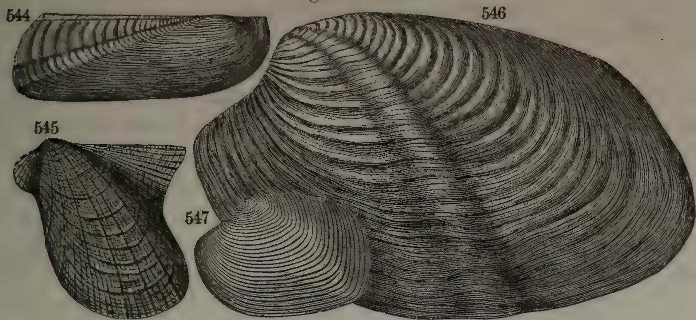
Brachiopods. — Fig. 536, Atrypa aspera; 537, A. reticularis; 538, Tropidoleptus carinatus; 539, Spirifer mucronatus; 540, Athyris spiriferoides; 541, Spirifer (Martinia) umbonatus; 542, Chonetes setigera; 543, Productus subalatus.

Lamellibranchs are more numerous than in former eras. The following figures, 544 to 547, show some of the characteristic species.

With this period commenced the genus *Goniatites* (Fig. 548) — a group of Cephalopods with Nautilus-like shells, but differing from *Nautilus* in having the siphuncle dorsal, and the septa with one or more flexures at the margin; in case of one flexure or more, there is always one on the dorsal margin, as in Fig. 548 *a*. The Goniatites became more and more complex in the flexures of the septa during the following periods of the Paleozoic, and afterward were replaced by the Ceratites and Ammonites, to which they are closely related.

Among the Articulates, there were species of Trilobites, one of

Figs. 544–547.



CONCHIFERS. — Fig. 544, Orthonota undulata ($\times \frac{2}{3}$); 545, Pterinea flabella ($\times \frac{1}{2}$); 546, Grammysia bisulcata; 547, Microdon bellistriatus.

which is represented in Fig. 549, and the tail portion of another in

Figs. 548–550.

CEPHALOPOD. — Fig. 548, 548 *a*, Goniatites Marcellensis. TRILOBITES. — Fig. 549, Phacops bufo; 550, Caudal extremity of Dalmanites calliteles.

550. There were also the earliest yet discovered of the remains of Insects, obtained at St. John, N. B. They are the wings of Neuropterous Insects, and one of these is represented in Fig. 550 *a* — the *Platephemera antiqua* of Scudder. It is related to the *Ephemeræ* or May-flies, species whose larves live in the water, and which frequent moist places, and therefore stood a good chance of becoming preserved as fossils.

Fig. 550 A.

Platephemera antiqua.

It was a gigantic species, measuring five inches in spread of wings. One species has what appears to be a stridulating organ, according to

Scudder; and Dawson thereupon observes that "the trill and hum of insect life must have enlivened the solitudes of the strange old Devonian forests." Insects appear to have been the only winged life of the Devonian and Carboniferous ages.

Vertebrates are represented only by fishes; and the species are of the Selachian (or Shark), Ganoid, and Placoderm groups, as in the Corniferous era. One of the Placoderms from the Black shale of Ohio, called *Dinichthys Hertzeri* by Newberry, had a head three feet long by two broad, and under jaws two feet long: the fish could hardly have been less than twenty feet in length. The remains are very numerous. A fin-spine (*Ctenacanthus vetustus*) a foot long, from the same shale, belonged to a shark probably fifteen feet long.

Characteristic Species.

1. Radiates. — Fig. 535, the Coral *Heliophyllum Halli* E. & H., common in the Hamilton, at Moscow, York, and elsewhere, and found also in England. The Encrinal limestone is made up of fragments of crinoidal columns.

2. Mollusks. — (*a.*) *Brachiopods.* — Fig. 536, *Atrypa aspera* Dalm., also European; 537, *A. reticularis*, regarded as the same species as that of the Corniferous period, but usually much larger and fuller, being sometimes nearly two inches broad; 538, *Tropidoleptus carinatus* H., in New York, Illinois, Iowa, Europe; 539, *Spirifer mucronatus* Con., very common; 540, *Athyris spiriferoides* H. (*Atrypa concentrica* of Conrad), — it has the spire internally of a *Spirifer;* 541, *Spirifer* (*Ambocœlia*) *umbonatus;* 542 *Chonetes setigera* H., found in both the Marcellus and Genesee shales; 543, *Productus* (*Productella*) *subalatus* H., Rock Island, Ill. A shell closely like the *S. umbonatus*, but higher, occurs in Iowa and Illinois, and is named *Cyrtina umbonata* by Hall. *Spirifer granuliferus* H. is a large Hamilton species, having a granulated surface.

(*b.*) *Lamellibranchs.* — The species are often of large size; but none yet described have a sinus in the pallial impression. Fig. 544, *Orthonota undulata* Con.; 545, *Pterinea flabella* Con.; 546, *Grammysia bisulcata* Con. (*Hamiltonensis* of Verneuil), — also European, in the Eifel; 547, *Microdon bellistriatus* Con.

(*c.*) *Gasteropods.* — A few species have been described. They are all without a beaked aperture, like those of older time. The *Bellerophon patulus* H. is a broad species of the genus, with a flaring aperture. *Platyceras ventricosum* Con., *Isonema* (*Holopea*) *depressa* M. & W.

(*d.*) *Cephalopods.* — Fig. 548, *Goniatites Marcellensis* Van., a species sometimes a foot in diameter, occurring in the Marcellus shale; 548 *a*, dorsal view. Two small species, the *G. uniangularis* and *G. punctatus*, are reported by Conrad from the Hamilton beds. The genus *Orthoceras* is represented by a few species of moderate size; there are also *Gomphoceras turbiniforme* M. & W., *Cyrtoceras sacculum* M. & W., and *Gyroceras* (?) *constrictum* M. & W., in Illinois and Indiana.

3. Articulates. — (*a.*) *Crustaceans.* — The Trilobites *Phacops bufo* (Fig. 549) and *Dalmanites Boothii* H. (*D. calliteles*) (Fig. 550, representing the posterior extremity) are common in the Hamilton beds; also *Phacops rana* Green. *Eurypterus pulicaris* Salter, a minute species, occurs at St. John, New Brunswick, and with it a peculiar crustacean, Macrural in habit, the *Amphipeltis paradoxus* Salter.

(*b.*) *Insects.* — At St. John, N. B., besides the *Platephemera antiqua* Sc. (Fig. 550 A.), there are two other Neuropters with a spread of wing of $3\frac{1}{2}$ inches, and a fourth, the *Xenoneura antiquorum* Sc., with the same $2\frac{1}{2}$ inches; this last is the one having the stridulating organ alluded to above.

4. Vertebrates. — The fossil fishes of the Hamilton rocks are of several genera and species. In the Gaspé sandstones occur remains of *Cephalaspis*, and "apparently

Coccosteus, Ctenacanthus, and *Leptacanthus*" (Dawson). The gigantic *Dinichthys* of Newberry, from the Black Shale of Ohio, occurs in great concretions, some of them twelve feet in diameter. Remains of a species of *Palæoniscus* have been found in the top of the same shale, near Danville, Ky. (F. H. Bradley.)

General Observations.

Geography. — The positions and nature of the Hamilton beds indicate similar geographical conditions to those of many earlier periods, — that a shallow sea covered New York and spread widely to the west, and that many changes were experienced in the water-level. The beds are to a great extent mud-beds, whence we learn that they were deposited in quiet waters: the fossils are marine, proving marine waters. The beds in New York are thickest about its central parts, and yet spread to its eastern and western limits, excepting the uppermost, the Genesee shale, which is not known in the eastern part; they are partly calcareous in the lower part of the Marcellus beds, proving that the change from the condition of the limestone-making Corniferous period was gradual; limestone layers occur higher up, at intervals, indicating changes of level, which favored at times the growth of Crinoids and Corals; ripple-marked flags make up some layers, proving, by their evenness and extent, and the regularity of the lamination, that the sea, at the time of their formation, swept over extensive sand-flats, coming in over the present region of the Hudson River or of New York Bay. The existence of a barrier of sand along the ocean, such as is thrown up and at intervals removed again by the waves, would account for the varying conditions and also for changes in the living species by extermination.

Moreover, while these mud-accumulations were here in progress, there were Hamilton limestones forming in some of the Western States, indicating again the existence of the Interior or Mississippi sea, — a feature in a large part of both Silurian and Devonian geography; and then the wide-spread, but thin, Hamilton black shale, almost destitute of fossils, and very bituminous, indicating probably quite shallow waters over the Interior basin, — yet not so shallow but that fishes could live abundantly through them.

The Appalachian region was still an area of vastly the thickest deposits, and hence of the greatest change of level by subsidence; and the great thickness of the formation (1,000 feet) in central New York makes it another example of the prolongation of the subsiding Appalachian region northward over southern New York. This fact and the thinning of the beds toward the Hudson River indicate that the Green Mountain region was above the sea, so that the great New York bay, alluded to in the observations on the Oriskany beds, was still outlined on the east, although communicating westward more or less perfectly with the Interior basin.

Life. — The land plants of the Hamilton beds prove that, over the rocks and soil of the emerged continent, with its islands, there were forests and jungles of Conifers, Sigillarids, Lepidodendrids, Calamites, and Tree-ferns. As to animal life, the Hamilton beds give us the first evidence that the sub-kingdom of Articulates contained *terrestrial* species. It is altogether probable that, besides Insects, there were also Myriapods (Centipeds), and Spiders, the other kinds of terrestrial Articulates. All these types may have appeared much earlier, with the terrestrial vegetation of the Upper Silurian; but there is as yet no positive assurance of this.

3. CHEMUNG PERIOD (11).

Epochs. — 1. PORTAGE, or that of the Portage group (11 *a*); 2. CHEMUNG, or that of the Chemung group (11 *b*).

I. Rocks: kinds and distribution.

The Portage group in New York consists of shales and laminated or shaly sandstones. Westward, the shales increase in proportion, and eastward the sandstones; and there are changes in the fossils, corresponding with these variations. The rocks have a thickness of 1,000 feet on the Genesee River, and 1,400 near Lake Erie. (Hall.) They are well developed about Cayuga Lake, but have not been recognized in the eastern half of the State of New York.

The Chemung group extends widely over the southern tier of counties of New York, and consists of sandstones and coarse shales, in various alternations. The thickness has been estimated at 1,500 feet near the longitude of Cayuga Lake, and less toward Lake Erie and beyond.

Rocks of this period fail over a large part of the Interior Basin, nothing intervening between the *Black shale* and the Subcarboniferous.

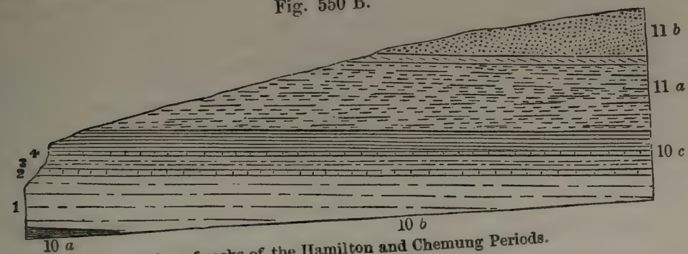
To the south and southwest of New York, in Pennsylvania, and beyond along the *Appalachian region*, the corresponding beds have great thickness, amounting in some places to more than 3,000 feet. They are sandstones, as in New York. The upper part of the sandstone beds about Gaspé are referred to this period; and also the plant-bearing beds at Perry, Maine.

The beds in New York abound in ripple-marks, obliquely-laminated layers, mud-marks and cracks from sun-drying, — evidences of the existence of extensive exposed mud-flats, of sandy or muddy areas swept by the waves, and of tidal currents in contrary movement through the shallow waters.

In western New York, the lower beds are the Cashaqua shales; next, the Gardeau shales and flags; then, above these, the Portage sandstones.

In this section, from one by Hall, taken in Yates County, N. Y., 10 *a*, 10 *b*, 10 *c* are

Fig. 550 B.



Section of rocks of the Hamilton and Chemung Periods.

rocks of the Hamilton period; *a*, the Marcellus shale; *b*, the Hamilton group; *c*, the Genesee shale; and, in the Hamilton group, 2 is the Encrinal limestone, and 4 the Tully limestone; 11 *a* is the Portage group, 11 *b* the Chemung group.

Westward of New York, the Portage and Chemung groups are continued into Ohio, just along the south side of Lake Erie; and the Black shale of Ohio and the States west and south, is regarded by Newberry as partly of Portage age.

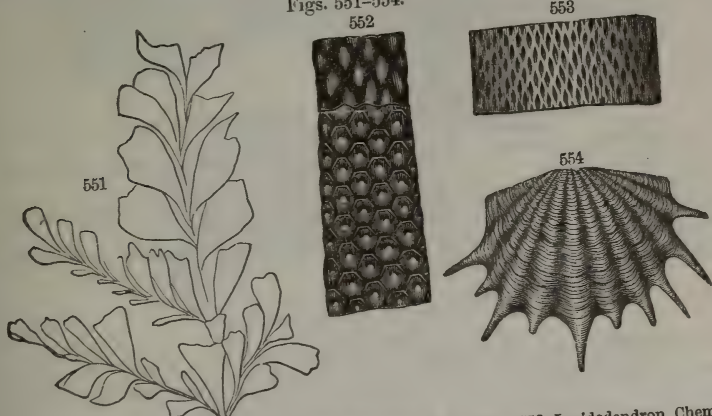
II. Life.

The fossils of the Chemung period are almost wholly different in species from those of the Hamilton.

1. *Plants.*

Besides the *Cauda-galli* and other Sea-weeds, there are remains of many land-plants. They are, in genera, like those of the preceding period. Some of the kinds are here represented.

Figs. 551–554.



PLANTS. — Fig. 551, Cyclopteris Halliana; 552, Sigillaria Vanuxemi; 553, Lepidodendron Chemungense. BRACHIOPOD. — Fig. 554, Atrypa hystrix.

A large-leaved fern, from the Chemung of Gilboa, N. Y., is named by Dawson *Cyclopteris Gilboensis.* The form somewhat resembles Fig. 557 A, p. 279, of a Catskill species.

2. *Animals.*

The Portage beds, though abounding less in fossils than the Chemung, contain various species of *Crinoids*, *Brachiopods*, *Lamellibranchs*, (*Aviculopectens*, *Aviculæ*, and others), *Bellerophons*, and *Goniatites*. A large Crinoid — the *Poteriocrinus* (?) *ornatissimus* M. — occurs in great numbers, broken to fragments, through a small area in the town of Portland, N. Y., on Lake Erie shore.

The Chemung group in New York affords great numbers of *Aviculæ;* many Brachiopods, including broad-winged *Spirifers*, and some *Producti;* among Cephalopods, a huge *Goniatite* (four or five inches in diameter); and rarely a *Trilobite*.

Characteristic Species.

1. *Plants.* — Fig. 551, *Cyclopteris* (or *Palæopteris*) *Halliana* Göpp., Upper Chemung beds; 552, *Lepidodendron Chemungense* Hall, from near Elmira, N. Y.; 553, *Sigillaria Vanuxemi* Göpp., from near Owego, N. Y.; *S. simplicitas* Vanuxem, from near North Bainbridge, N. Y. A Coniferous fossil wood, from Schoharie County, N. Y., has been named *Ormoxylon Erianum* by Dawson. At Perry, Me., occur *Lepidodendron Gaspianum* Dn., *Leptophleum rhombicum* Dn., *Cyclopteris Jacksoni* Dn., *C. Halliana* Göpp., *C. Rogersi* Dn., *C. Brownii* Dn., *Caulopteris Lockwoodi* Dn., *Anarthrocanna Perryana* Dn., *Stigmaria pusilla* Dn., and others, there being very few of the St. John species. Some species are the same that occur in the Subcarboniferous beds, particularly the marsh species.

Figs. 555–557.

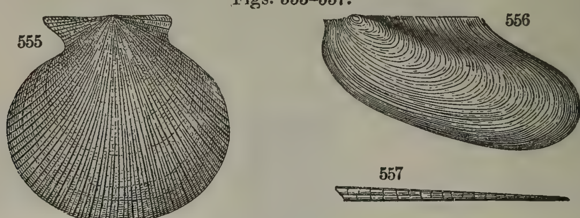


Fig 555, Aviculopecten duplicatus; 556, Pteronites (?) Chemungensis; 557, Orthoceras acicula.

2. *Animals.* — Fig. 554, *Atrypa hystrix* H.; Fig. 555, *Aviculopecten duplicatus* H.; Fig. 556, *Pteronites* (?) *Chemungensis* H.; Fig. 557, *Orthoceras acicula* H.

Teeth of fishes of the genus *Onychodus*, and others, have been found in the beds at Franklin, Delaware County, N. Y.

III. General Observations.

Geography. — The character of the beds — the shales and shaly sandstones — which spread over western and southern New York and southwest along the Appalachian region, becoming more shaly toward the western limit of the State, and more sandy in the opposite direction, tells nearly the same story with regard to the geography of this portion of the continent as the beds of the Hamilton period. The rocks were

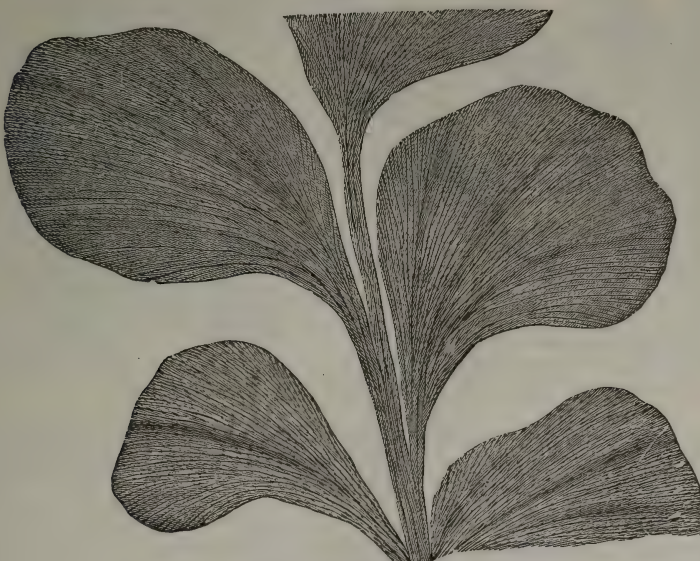
largely shallow-water or sand-flat formations, as shown by the ripple-marks, shrinkage-cracks, and oblique lamination; and they therefore indicate, by their great thickness, a subsidence during their progress, to a corresponding extent, and, further, that this subsidence or change of level affected most the Appalachian region. The shallow sea extended westward along the southern border of Lake Erie. But it is probable that, over the larger part of the Interior basin, the land lay mostly above the water level. It is difficult, otherwise, to account for the absence of beds between the Black Shale and the Subcarboniferous

4. CATSKILL PERIOD (12).

I. Rocks: kinds and distribution.

The rocks of the Catskill period are shales and sandstones of various colors, in which red predominates. The sandstones are far more extensive than the shales, and pass into conglomerates or coarse grit-rock, and also into a rough mass looking as if made of cemented fragments of hard slate. The upper part is generally a conglomerate. There are ripple-marks, oblique lamination, and other evidences of sea-shore action in many of the strata. Some of the layers are partially calcareous.

Fig. 557 A.



FERN. — *Cyclopteris obtusa.*

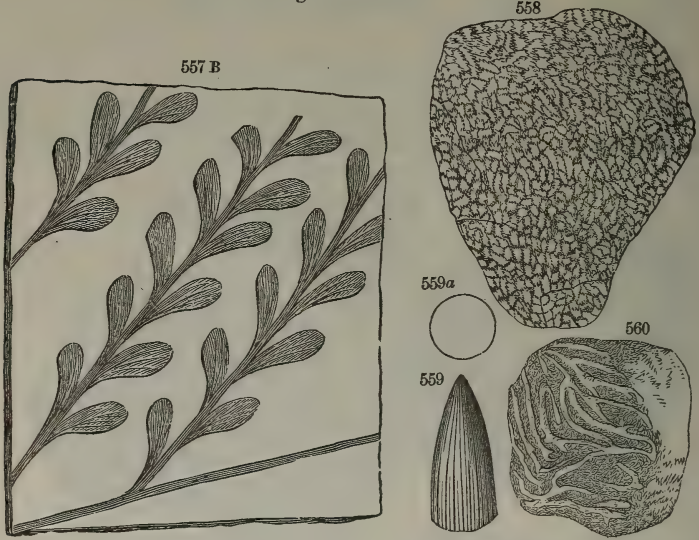
The formation, instead of thickening to the westward, in New York,

like those preceding it in time, thins out in that direction, and thickens toward the Hudson, being two or three thousand feet thick in the Catskills. It stretches south along the Appalachian region, beneath the Coal formation of Pennsylvania and Virginia, where it is 5,000 or 6,000 feet thick. It is eminently an *Appalachian* formation.

II. Life.

The rocks afford but few relics of life. The plants are related to those of the preceding period. A portion of one large fern, Devonian in character, is represented in Fig. 557 A; and another of the same

Figs. 557 B–560.



FERN. — Fig. 557 B, Cyclopteris minor. FISH REMAINS. — Fig. 558, scale of Holoptychius Americanus; 559, tooth, id.; 559 *a*, section of tooth; 560, scale of Bothriolepis Taylori.

genus, in Fig. 557 B — a genus characteristic especially of the Devonian (p. 271). There were also other ferns, besides *Lepidodendra*, *Sigillaria*, *Calamites*, etc.

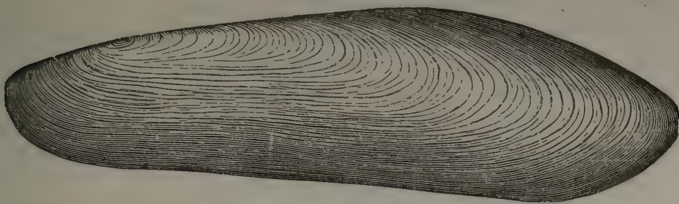
Remains of large fishes occur in the beds. Figs. 558, 560 represent scales of two species, and 559, a tooth of the first of them. The fish that had this tooth was a very large Ganoid, and resembled that represented in Fig. 569, page 286.

Characteristic Species.

1. *Plants.* — The fern, of which a portion is represented in Fig. 557 A, was over a foot broad; it was obtained at Montrose, Pa., by H. A. Riley. *Cyclopteris minor* (*Nœggerathia minor* Lsqx.), Fig 557 B, is from Pottsville, Pa.

2. *Animals.* — Among animals, no Corals, Crinoids, Brachiopods, or Trilobites are yet known; the coarse character of the beds accounts for their absence. There are some Lamellibranchs, such as (Fig. 561) the *Modiola angusta* (*Cypricardia angusta* Con.), and a few other species, and a *Euomphalus;* these, with fragments of fishes, make up about

Fig. 561.



LAMELLIBRANCH. — Modiola angusta.

all that is yet known respecting the animal fossils of the beds. Among the fishes, there are (Fig. 558) *Holoptychius Americanus* Leidy (559 being a tooth of the same, and 559 *a*, a section of it); 560, *Bothriolepis Taylori* Newb. (*Sauripteris Taylori* H.) The latter species was of large size, a portion of one of the fins found in New York indicating a length of more than a foot for the entire fin.

III. General Observations.

Geography. — The location of the Catskill beds in eastern New York, instead of central or western (like the Hamilton and Chemung), and their thickness there, seem to show that a great geographical change preceded the opening of the period. The Appalachian subsidence, instead of extending north over central New York, involved the Hudson River valley, far to the eastward; and the amount of subsidence both here and in Pennsylvania and Virginia was much greater than in the preceding periods. After this, New York State, excepting a border on the south, lay to the north of the region undergoing progress through new formations: the greater part of it was probably part of the dry land of the growing continent; for the rocks of the Coal age, with the small exception alluded to, do not spread over it.

If the view presented be correct, there is a bold transition from the closing period of the Devonian age to the opening of the Carboniferous. The former was a period in which the grand Appalachian subsidence (as in other parts of the Devonian) reached north into the State of New York, while in the latter it hardly passed the limits of Pennsylvania. The former was characterized by dry land, over a large portion of the great Interior Continental basin; the latter, by a wide-spread and clear, though not deep, sea, growing Crinoids and forming limestones; for the Subcarboniferous limestone formations are among the most extensive in the geological series, and crinoidal remains are in great profusion.

2. FOREIGN DEVONIAN.

I. Rocks: kinds and subdivisions.

The Devonian rocks occur as surface-strata in most of the countries of Europe, and in parts of all the other continents.

In the British Isles, they are exposed to view in southern Wales and the adjoining county of Herefordshire; in the peninsula of Devonshire and Cornwall; along the southern flank of the Grampians, and on the northwestern side of Lammermuir from Dunbar to the coast of Ayrshire, in the valley of the Tweed and elsewhere, in Scotland; also in Ireland, and in the Isle of Man.

On the map, Fig. 681 A, p. 344, the Devonian areas are distinguished by vertical lines.

The strata in England and Scotland have long gone by the name of the Old Red Sandstone, — red sandstone being the prevailing rock in Wales and Herefordshire, as well as in Scotland. In Devonshire and Cornwall, these rocks are slates and limestone, instead of red sandstone.

The beds of Wales are argillaceous shales or marlytes, of red and other colors, with some whitish sandstone and impure limestone, overlaid by red sandstone which passes above into a conglomerate; and the whole thickness is estimated by Murchison at 8,000 or 10,000 feet. The limestone is concretionary, and is called *Cornstone.*

In Scotland, the following subdivisions have been made out: —

3. Upper.	3. Yellow sandstone; containing *Holoptychius*, etc. 2. Concretionary limestone. 1. Red sandstone and conglomerate.
2. Middle.	Gray sandstones and shales; containing *Onchus*, *Ctenodus*, *Polypterus*, *Osteolepis*, *Pterichthys*, etc.
1. Lower.	3. Red and variegated sandstone. 2. Bituminous schists; containing *Dipterus*, *Pterichthys*, *Coccosteus*, *Cephalaspis*; also *Eurypterus*, *Pterygotus*, etc. 1. Conglomerate and red sandstone.

In Devonshire and Cornwall, the strata are, according to Sedgwick: —

4. Petherwin group.	2. Petherwin slate and Clymenia limestone. 1. Marwood sandstones.
3. Dartmouth group.	Roofing-slates and quartz, with variegated sandstones above, in north Devon.
2. Plymouth group.	3. Red sandstone and flagstone. 2. Calcareous slates. 1. Plymouth limestone.
1. Liskeard or Ashburton group.	

The Clymenia limestone has been referred by some to the Lower Carboniferous.

In the south of Ireland, Devonian beds occur as a thin deposit in the counties of Kilkenny and Wexford, rapidly thicken in Waterford, and have great bulk in Cork and Kerry (Jukes). The rocks are red sandstones and slates, like those in the upper part of the series in Wales.

In the Eifel (Rhenish provinces), there are, below, slates and sandstones; next, the great Eifel limestone, the equivalent, apparently, of the Corniferous; above this, slates, with an intermediate limestone, — the whole termed the *Cypridina slates*, and perhaps Lower Carboniferous in age.

In Russia, the Devonian formation is exposed over a great extent of country. The rocks are mostly marlytes and sandstones, with some laminated limestones. According to Kutorga, the prevailing order is — marlytes below, then sandstones, then argillaceous limestone.

There is thus a great diversity in mineral character, and no conformity in the subdivisions of the Devonian with those in America. As already explained, these subdivisions are in general due to causes that have acted too locally to be often alike and synchronous in very distant regions.

II. Life.

1. *Plants.*

Europe and Britain have afforded, in addition to sea-weeds, remains of plants mostly related in genera to those of the United States; so that the other continents besides America had their Ferns, Lycopods, Calamites, and Conifers. Devonian plants have been reported also from Queensland, Australia.

Among the Devonian plants of Ireland, in beds that contain also remains of *Coccosteus* and *Glyptolepis*, there are *Cyclopteris Hibernica* Forbes, *Sphenopteris Hookeri* Baily, *S. Humphriesiana*, *Calamites radiatus* Br., *Lepidodendron Veltheimianum* Sternb., *Knorria acicularis* Göpp., *Cyclostigma minutum* Haughton, *C. Kiltorkense* Haughton, and others. Heer has identified *Calamites* (*Bornia*) *radiatus* Brngt., *Lepidodendron Veltheimianum*, *Cyclopteris Rœmeriana* Göpp. (a European species near *C. Hibernica*), *Sphenopteris Schimperi* Göpp., *Knorria imbricata* Sternb., *Cyclostigma minutum* and *C. Kiltorkense*, etc., in beds of sandstone on Bear Island (74° 30′ N.), which he refers to the lower part (his *Ursa* stage) of the Subcarboniferous, fifteen out of the eighteen species there found being known and partly wide-spread species, and several occurring in the Ursa beds of the Vosges and Black Forest. In a shale, regarded as Devonian, under the Subcarboniferous of Moresnet, occurs *Cyclopteris Rœmeriana*, with *Spirifer disjunctus* Sow.

2. *Animals.*

The range of animal life was similar to that of America. A few species of Europe and America were identical; but the great majority were distinct: as regards genera, the identity was very nearly complete.

Corals were abundant in Europe, especially *Favosites* and the Cyathophylloid species; and coral-reefs were forming in the Eifel and some other parts. Mollusks were most abundantly represented by *Brachiopods*, and Crustaceans by *Trilobites* and the little *Ostracoids*. There were also large species of *Eurypterus*, *Pterygotus*, and allied forms, some of which had the length, enormous for Crustaceans, of five feet. For details respecting these Entomostracans, see Woodward's "Memoir," published by the Paleontographical Society.

Among Brachiopods, *Spirifers* were very common; and the genus *Productus* made its first appearance, along with others of less prom-

inence. *Goniatites* also (a genus of Cephalopods) was a new type, and became well represented before the close of the age. Another genus, *Clymenia* (Fig. 562), was represented by many species in the Upper Devonian.

The sub-kingdom of Vertebrates included numerous fishes of the orders of *Selachians* and *Ganoids*, as in America. A few are represented, of reduced size, in Figs. 566–570. Figs. 566, 567 represent two of the *Placoderms* — one that moved, unlike most fishes, by means of side paddles; and the other, one that sculled with its tail, in ordinary piscatory style.

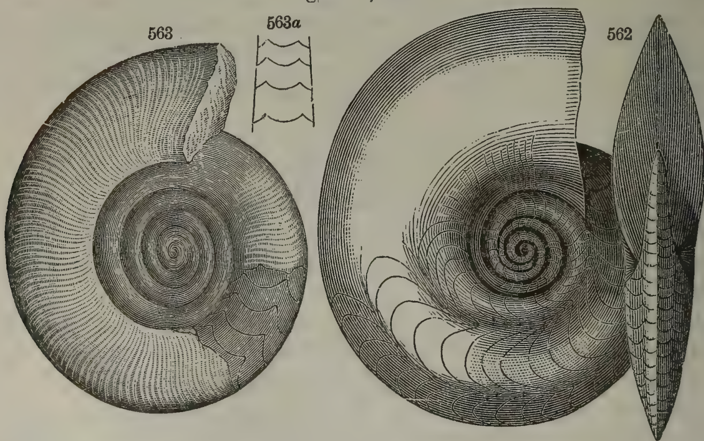
Characteristic Species.

1. Radiates. — Among Radiates, there were species of *Pentremites*, the earliest in Europe of the group of Blastoid Crinoids. The Corals included *Cyathophyllum cæspitosum* Goldf., *Heliolites porosa* E. & H., *Pleurodictyum problematicum* Goldf., *Aulopora serpens* Goldf.

2. Mollusks. — *Brachiopods* included species of *Orthis*, *Strophomena*, *Atrypa*, *Rhynchonella*, *Spirifer*, *Chonetes*, etc.; besides *Productus* and *Stringocephalus*, which are not known in Great Britain before the Devonian.

Lamellibranchs were numerous, of the genera *Avicula*, *Aviculopecten*, *Pterinea*, *Nucula*, *Conocardium;* also of *Arca*, *Grammysia*, *Megalodon*, etc.; also *Anodonta Jukesii*, a freshwater species. Fig. 241, p. 173, is the *Calceola sandalina* (so called from the sandal-like shape of the shell). This genus characterizes the *Calceola schist*, which underlies the great Devonian limestone of the Eifel. *Gasteropods* (all without beaks) of the old genera *Murchisonia*, *Euomphalus*, *Pleurotomaria*, *Loxonema*, *Bellerophon*, etc.

Figs. 562, 563.



CEPHALOPODS. — Fig. 562, Goniatites retrorsus; 563, Clymenia Sedgwickii; 563 *a*, dorsal view of septa.

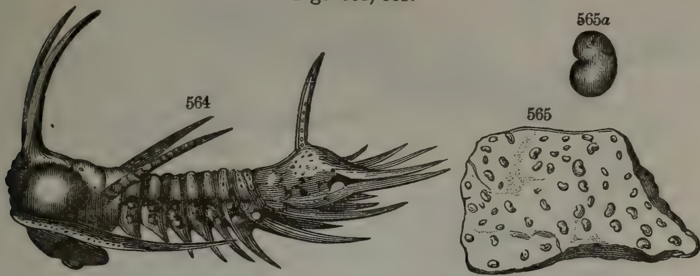
There were others also of the new genus *Porcellia*, which is near *Bellerophon*, and somewhat resembles an Ammonite in form, but has a deep dorsal slit in the aperture of the shell.

Cephalopods include a few species of the Orthoceras family, — also *Nautili*, and several species of the new genus *Goniatites*, of the Ammonite family, and of another,

called *Clymenia*. Fig. 562, *Goniatites retrorsus;* Fig. 563, *Clymenia Sedgwickii*. The shell in *Clymenia* has the form of the Ammonites, but, unlike the Goniatites and Ammonites, the siphuncle is ventral instead of dorsal; and the septa have no distinct dorsal lobe on the medial line, as shown in Fig. 563 *a*.

3. **Articulates.** — There were a number of species of Trilobites, though fewer than in the Silurian: the genera *Phacops* and *Dalmanites* were common. *Homalonotus* had European species; and one, *H. armatus*, had spines on the head, and two rows along the back. This spinous feature appears to have reached its maximum in the Devonian *Arges armatus* (Fig. 564), and some species of *Acidaspis*.

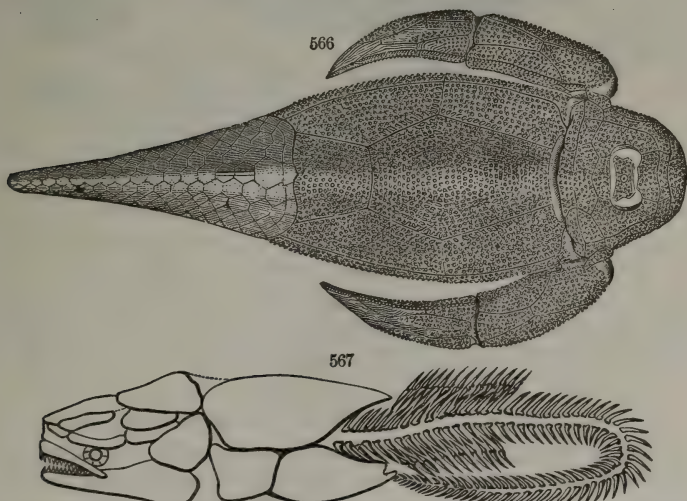
Figs. 564, 565.



CRUSTACEANS. — Fig. 564, Arges armatus; 565, Slate containing Cypridina serrato-striata, natural size; 565 *a*, same, enlarged.

Minute Ostracoids, referred to the genus *Cypridina*, abound in the *Cypridina slate*, giving this name to the beds; Fig. 565 represents a portion of the slate or shale, with the shells of the *C. serrato-striata* on its surface, natural size, and 565 *a*, one of them

Figs. 566, 567.



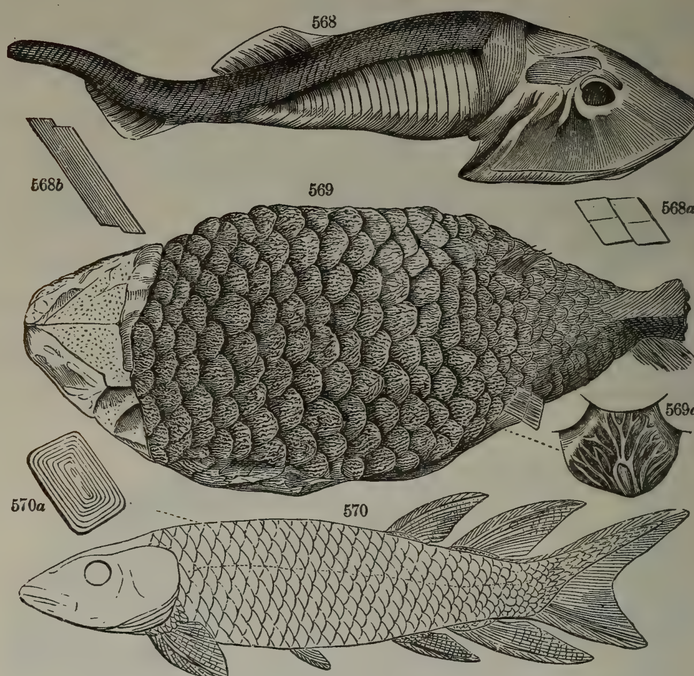
PLACODERMS. — Fig. 566, Pterichthys Milleri (× ⅜); 567, Coccosteus decipiens (× ¼).

enlarged. There were also other *Ostracoids*. The *Præarcturus gigas* Woodward, from the Old Red Sandstone of Herefordshire, is a gigantic Isopod crustacean; and *Stylonurus Scoticus* Wd., another from the Old Red of Forfarshire. They must have been over a foot long.

4. Vertebrates. — In the Devonian rocks of Great Britain and Europe, large numbers of species of fishes have been found.

Among the Placoderms, which occur in the two lower divisions, there were two prominent groups. Fig. 566, *Pterichthys Milleri* Ag., represents one; and Fig. 567, *Coccosteus decipiens* Ag., represents the other. Also Fig. 568, *Cephalaspis Lyellii* Ag.; Figs. Figs. 568 *a*, 568 *b*, scales of the same: a type sometimes referred to the Placoderms. Of other Ganoids, there were, Fig. 569, a *Holoptychius;* Fig. 569 *a*, scale, id.; Fig. 570, *Dipterus macrolepidotus*, Sedgw. & Murch.

Figs. 568–570.



GANOIDS. — Fig. 568, Cephalaspis Lyellii (× ⅔); 568 *a*, *b*, scales, id.; 569, Holoptychius (× 1/7); 569 *a*, scale, id.; 570, Dipterus macrolepidotus (× ½); 570 *a*, scale, id.

Species of *Pterichthys, Diplopterus, Glyptolepis, Dendrodus, Platygnathus*, etc. *Holoptychius* (Fig. 569) belongs to the *Upper* Devonian only, and also to the early Carboniferous. *Pterichthys* (*Asterolepis*) *Asmusi* Ag., whose remains occur both in Russia and Scotland, is supposed to have been twenty to thirty feet long.

3. GENERAL OBSERVATIONS ON THE DEVONIAN AGE.

American Geography. — 1. *General features.* — The Archæan area, which had been enlarged on the north by successive additions from emergence during the Silurian, continued expanding in the same direction, during the Devonian; and, at its close, the State of New York formed a part of the land. For, as seen on the map, p. 165, the rocks which succeed one another reach less and less far northward, indicating

that there was some progress southward with each period. Nearly all of Eastern Canada and New England was probably part of the dry continent, from the close of the Lower Devonian, there being no Upper Devonian or Carboniferous rocks over these regions, excepting in part of Nova Scotia, and near the sea border of Canada, New Brunswick, eastern Maine, and southeastern New England.

The general map on page 144 shows the area over which the Silurian and Devonian formations are now uncovered in other parts of North America. We cannot positively conclude that no later rocks ever existed over these areas; for extensive strata may have been washed away in the course of subsequent changes. Yet the progress of the emerged land southward, noted in New York, is apparent also along the region of Ohio and Wisconsin; and there was extension also from the Archæan axis of the far north, westward and eastward: so that a general expansion of the old Archæan land had taken place by additions to all of its borders. South of New York, and over a large part of the continent, the surface was still liable to alternate sinking and rising, and was therefore open to new formations.

North America was to a great extent a continental sea, with the amount of land that was permanently dry very limited, as compared with the present finished continent. In place of the Rocky Mountains and Appalachians, there were only islands, reefs, and shallow waters, marking their future site; for Carboniferous strata and others of later age cover the slopes of many of the Western mountains, and a limestone of the Carboniferous age exists on them at a height of 13,000 feet above the sea. The Appalachians also contain, in their structure, rocks of the Devonian and Carboniferous eras. The Green Mountains were above the water, through the Devonian, but had only part of their present height.

It follows, from the limited area of the land and the absence of high mountains, that there were no large rivers at the time. With the close of the Devonian, the Hudson River may have existed with nearly its present limits; the Connecticut and some other New England rivers may have begun their work; and, in Canada, the Ottawa and other streams drained the northern Archæan. Even the St. Lawrence, above Montreal, may have been a fresh-water stream.

3. *Geographical changes.* — The history of the periods of the Devonian has been shown to be, like that of the Silurian periods, a history of successive oscillations in the continental level, — the position of the accumulating deposits varying more to the east or to the west with the varying location of the subsiding or emerging areas. Throughout the whole, the Appalachian region continued to be well defined. Its Devonian deposits consist mainly of shales and sand-

stones, and have a total thickness of not less than 15,000 feet; while, in the West, the rocks are for the most part limestones, with a thickness of less than 500 feet.

Hence, the oscillations of level over the Interior basin were small, as compared with those of the Appalachian region. Moreover, the prevalence of limestone strata in the basin is evidence that the great mediterranean sea of the Silurian age was continued far into the Devonian, opening south into the Atlantic and Gulf of Mexico, and reaching north probably to the Arctic Ocean. Through some parts of the west, the Niagara and Corniferous limestones — the formations of that interior sea — follow each other with but little interruption.

European Geography. — The European continent in the Devonian age could not have had the simplicity of features and movement that characterized the American. It is obvious from the great diversity of the Devonian rocks — sandstones at one end of Britain and limestones at the other, limestones in the Eifel on the Rhine and almost none in Bohemia — that the continent had not its one uniform interior sea, like North America, but was an archipelago, diversified in its movements and progress.

There may have been proportionally more elevated heights over the area; but it is still true that there was little of it dry; that the loftier mountains had not been made, — the Alps and Pyrenees being hardly yet in embryo; and that, with small lands and small mountains, rivers must have been small.

Life. — The expansion of the types of *land-plants*, *insects*, and *fishes* especially marks the Devonian age.

The progress of life during the Devonian is further seen in —

(*a.*) The introduction of many new genera under old tribes; for example, *Productus* among Brachiopods, which began in America in the Corniferous period, and had its maximum display, and also its extinction, in the Carboniferous age; *Goniatites* among Cephalopods, which had its earliest American species in the Hamilton period, and became extinct at the same time with *Productus* — a genus of interest, as it is the first of a family (that of Ammonites) which had a wonderful extension under other genera in the Reptilian age, and became extinct at the close of that age; *Nucleocrinus* (Fig. 492), an early form of the *Pentremites*, another of the eminently Carboniferous types.

(*b.*) The complete or approximate extinction of tribes: as that of the *Cystids*, which disappeared with the Oriskany period in America and the Eifel limestone in Europe; that of *Favistella*, *Heliolites*, and other genera of Corals and Crinoids; that of *Atrypa*, *Stringocephalus*, and other genera of Brachiopods; that of the Chain-coral, or *Halysites*.

which does not appear above the Upper Silurian in America, but is found in the Eifel limestone in Europe; that of *Trilobites*, which, after there had been, under a succession of genera, over 1,700 species, came nearly to its end with the Devonian, the old genera being all extinct, and only three new ones appearing in the Carboniferous, to close off this prominent Paleozoic type; the *Orthoceras* family, species of which were few after the Devonian age. Extinction here means merely no reappearance among known fossil remains. The types may have long afterward had representatives in the deep ocean if not in some shallow seas. Lovèn reports the existence of a Cystid among the living species of the deep Atlantic.

(*c*.) In the historical changes in tribes or genera: for example, the *Spirifers*, which began in narrow species in the Upper Silurian, became broad-winged and very numerous in the Devonian, and continued thus into the Carboniferous; the species of *Productus*, the earliest of which were very small and few, were afterward of large size and numerous.

Each of these points admits of extensive illustration; but the above is sufficient to give an idea of the kind of progress life was undergoing. Each period had its new species or tribes, and its extinctions, and often, also, there were many successive faunas in a single period. Families and tribes were in constant change; and, through all these changes, the system of life was in course of development.

Climate. — The occurrence in the Arctic region of Devonian species, of the Hamilton era of the United States (p. 266), shows that there was little diversity of temperature at that time between the temperate and Arctic zones.

4. DISTURBANCES CLOSING THE DEVONIAN AGE.

In eastern Canada, Nova Scotia, and Maine, the Devonian and Silurian strata are uplifted at various angles beneath unconformable beds of the Carboniferous; and many of them have undergone more or less complete metamorphism (Dawson, Logan, C. Hitchcock). Dawson says that "in the Acadian Provinces, in passing downward from the Carboniferous to the Devonian, we constantly find unconformability," and part of the granyte of Nova Scotia "belongs to the close of the Devonian." Again, in New Brunswick and Maine, the Devonian beds near Perry underlie unconformably the Carboniferous; the latter resting, with small dip, on the upturned edges of the plant-bearing Devonian strata. It appears then that an epoch of great disturbance over the Eastern-border region intervened between the Devonian and Carboniferous ages.

The results exceeded in extent those that occurred over this same region after the Carboniferous age. At this epoch, the raising of the region of Maine above the sea, which had been carried forward through its northern portion after the Corniferous, appears to have been completed; for no rocks later than Devonian are known to occur over it. The existence of Helderberg rocks — probably Upper Helderberg — in the Connecticut Valley has been stated on a former page; and it may be here added that the upper beds of the series, now mica slate, gneiss, and quartzyte, may be of the Hamilton period. The crystallization and upturning of these rocks of the Connecticut valley, as well as those of Lake Memphremagog and the St. Lawrence Valley, may have been a part of the events of this epoch. At this time too, the region of eastern New York, west of the Hudson, which, during the Catskill period — that of the closing Devonian — was subsiding and receiving thick marine formations, probably emerged from the sea, leaving only a narrow southern margin of the State under salt water.

The other events of this epoch of disturbance, over North America, are not made out. In the county of La Salle, Illinois, and that adjoining it on the southeast, there is a N. 33° W. anticlinal axis in the beds underlying the Coal-formation, as illustrated in

Fig. 571.

Fig. 571. But these underlying beds are Lower Silurian, including *a*, the Calciferous formation; *b*, St. Peter's sandstone; *c*, the Trenton limestone; and it is not certain, therefore, that the disturbance occurred directly before the Carboniferous age. In other sections in northern Illinois, the Niagara limestone is included among the upturned beds conformable to the Trenton, and hence the movement was not at the close of the Lower Silurian like that producing the Cincinnati uplift.

In Great Britain, Russia, and Bohemia, also, examples of disturbances between the Devonian and Carboniferous have been observed, but not in Central and Southern France.

But all these cases are small exceptions to the general fact that the Lower Carboniferous and the underlying rocks are conformable, almost the whole world over. The epoch of transition was not an epoch of general disturbance. There were extensive oscillations of level; but for the most part they involved no violent upturnings. The Carboniferous age opens with a period of marine formations; and the beds accumulated, in most regions where they occur, as a direct continuation of the deposits of the Devonian.

III. CARBONIFEROUS AGE.

The Carboniferous age is divided into three periods: —

I. The SUBCARBONIFEROUS PERIOD (13).

II. The CARBONIFEROUS PERIOD (14).

III. The PERMIAN PERIOD (15).

The Carboniferous age, both in America and Europe, commenced with a preparatory marine period, — the SUBCARBONIFEROUS; had its consummation in a long era of extensive continents, covered with forests and marsh-vegetation, and subject at long intervals to inundations of fresh or marine waters, — the CARBONIFEROUS; and declined through a succeeding period, — the PERMIAN, in which the marsh-vegetation became less extensive, and the sea again prevailed over portions of the Carboniferous continents.

American Geographical Distribution.

The rocks of the Carboniferous age lie at the surface, over large areas of North America, as shown on the accompanying map (Fig. 572), in which the black areas and those cross-lined or dotted on a black ground are of this age.

I. *Eastern-border Region.* — 1. A small area in Rhode Island, continued northward into Massachusetts.

2. A large area in Nova Scotia and New Brunswick, stretching eastward and westward from the head of the Bay of Fundy.

These two areas are now separated; but it is probable that they were once united along the region, now submerged, of the Bay of Fundy and Massachusetts Bay.

II. *Alleghany Region.* — This great area commences at the north on the southern borders of New York, and stretches southwestward across Pennsylvania, Western Virginia, and Tennessee to Alabama, and westward over part of eastern Ohio, Kentucky, Tennessee, and a small portion of Mississippi. To the north, the Cincinnati geanticlinal, or the low elevation extending from Lake Erie over Cincinnati to Tennessee, forms the western boundary.

III. *Interior Region.* — 1. The Michigan coal area, an isolated area wholly confined within the lower peninsula of Michigan.

2. The Eastern Interior area, covering nearly two thirds of Illinois, and parts of Indiana and Kentucky.

3. The Western Interior area, covering a large part of Missouri, and extending north into Iowa, and south, with interruptions, through Arkansas into Texas, and west into Kansas and Nebraska.

The Illinois and Missouri areas are connected now only through the

Fig. 572.

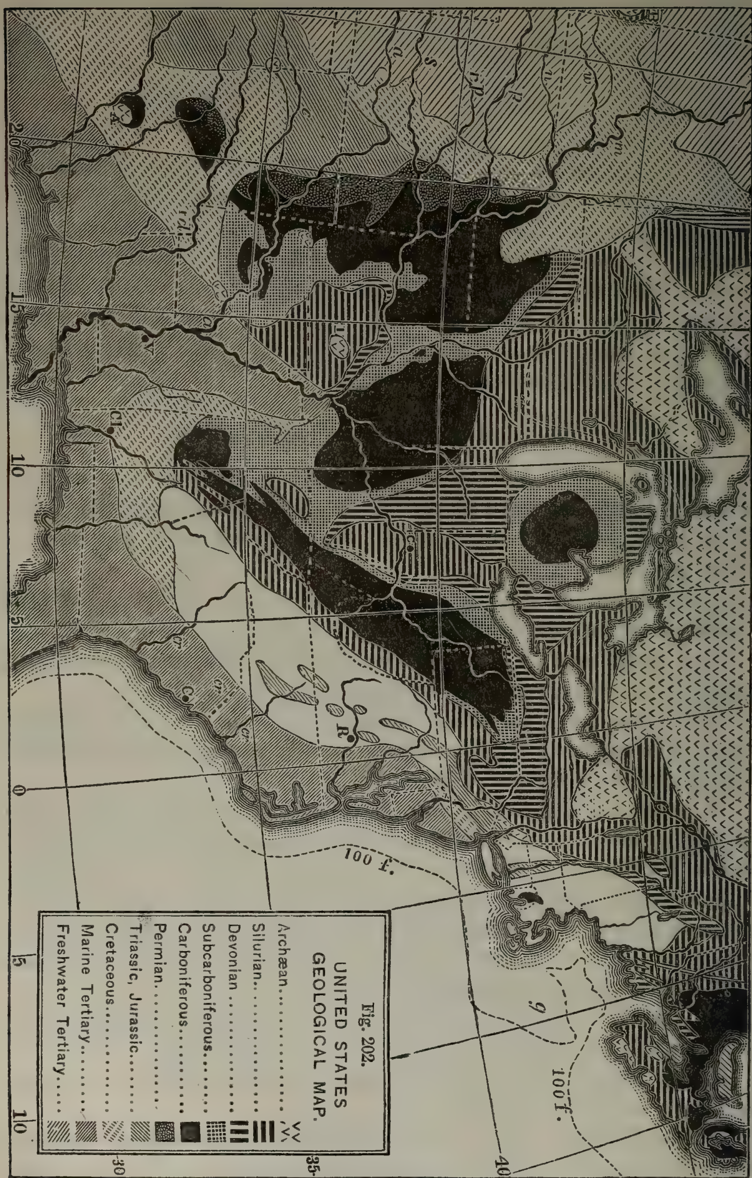


Fig. 202.
UNITED STATES
GEOLOGICAL MAP.
Archæan
Silurian
Devonian
Subcarboniferous
Carboniferous
Permian
Triassic, Jurassic
Cretaceous
Marine Tertiary
Freshwater Tertiary
100 f.
100 f.

Subcarboniferous rocks of the age; but it is probable that formerly the coal fields stretched across the channel of the Mississippi, and that the present separation is due to erosion along the valley.

Besides these, there are the following barren of coal, or nearly so.

IV. *The Rocky Mountain and Pacific Border Regions.* — 1. The great Basin and Summit area, embracing parts of Montana, Wyoming, Colorado, Utah, and Nevada.

2. The California area, in the northern half of California.

V. *The Arctic Region.* — In Melville Island, and other islands between Grinnell Land and Banks Land, on Spitzbergen, and on Bear Island north of Siberia.

The extent of the coal-bearing area of these Carboniferous regions is approximately as follows: —

Rhode Island area	500 square miles.
Alleghany area	59,000 square miles.
Michigan area	6,700 square miles.
Illinois, Indiana, West Kentucky	47,000 square miles.
Missouri, Iowa, Kansas, Arkansas, Texas . . .	78,000 square miles.
Nova Scotia and New Brunswick	18,000 square miles.

The whole area in the United States is over 190,000 square miles, and in North America about 208,000. Of the 190,000 square miles, perhaps 120,000 have workable beds of coal.

1. SUBCARBONIFEROUS PERIOD (13).

I. Rocks: kinds and subdivisions.

In the *Interior Continental region*, the Subcarboniferous rocks are mainly limestones. They are largely displayed in Illinois, Kentucky, Iowa, and Missouri, and have at some points a thickness of 1,200 feet. They also occur in Arkansas and Texas. To the eastward, the proportion of limestone diminishes. In Tennessee, the *lower* beds are siliceous, and the *upper*, limestone. In Michigan, there are about seventy feet of limestone, resting upon 480 feet of shales and sandstones; in Ohio there are over 600 feet of sandstones and shales, with twenty feet or less of limestone at top, in some parts.

In the *Appalachian Region* in Pennsylvania, the beds, instead of being limestones, are sandstones or shales, excepting small portions in the southwestern part of the State. The thickness increases from the westward and northward toward Pottsville and the Lehigh region, where in some places it is 4,000 to 5,000 feet. In Virginia, the beds are more calcareous, and the limestone increases in amount to the southwest. and continues to Alabama and Mississippi.

There are thin workable seams of *coal* in some of these Subcarboniferous beds of Pennsylvania, Virginia, western Kentucky, and southern Indiana, and also valuable beds of *clay-ironstone.*

The subdivisions of the Subcarboniferous rocks are best exhibited in the limestones of the era in the Mississippi valley or Interior Continental basin; and hence, in giving further details respecting the formation, they are first considered.

(*a*.) *Interior Continental Basin.* — In *Illinois*, the subdivisions, according to Worthen, — partly following those of Hall, — are the following, beginning with the oldest.

1. Kinderhook Group. — Consists of sandstones, grits, and shales, with thin beds of oölitic limestone; 100–200 feet thick. The "Choteau limestone," "Lithographic limestone," and "Vermicular sandstone and shales," of Missouri, are here included, and also the "Goniatite limestone" of Rockford, Indiana. It rests on the Devonian Black shale.

2. Burlington Group. — Limestone, with cherty layers at top, and nodules of hornstone through portions of the limestones; 25 to 200 feet thick. Much of it is excellent building stone.

3. Keokuk Group. — Mainly limestone, with thin-bedded cherty layers below along the junction with the Burlington limestone, gray limestone at middle, and a shaly, argillaceous, magnesian limestone above, often abounding in geodes of quartz, etc., called the Geode bed. The geodes vary from half an inch in diameter to twenty inches or more; and many are beautiful for their agates, or druses of quartz crystals, and some for crystallized calcite, dolomite, blende, pyrite, etc.

4. St. Louis Group. — Evenly-bedded limestone of Alton and St. Louis; oölitic limestone, three miles above Alton; and equivalent beds at Bloomington and Spergen Hill, Indiana; blue calcareous shales and arenaceous limestone at Warsaw. In some places 250 feet thick.

5. Chester Group. — Limestone, in three or four beds, with some intercalated shale and sandstone; occasionally 600 feet thick. Includes the "Pentremital" limestone, and the "Upper Archimedes" limestones. The Upper Archimedes has also been called the "Kaskaskia" limestone.

The whole series in southwestern Illinois has a thickness of 1,200 to 1,500 feet: it thins out rapidly to the north, and disappears before reaching Rock Island County, leaving the Coal-measures resting on the Devonian limestones.

In *Iowa*, according to C. A. White, the Carboniferous is the surface formation over all the State, excepting the northeastern third where the rocks are older, and an area in the northwestern part which is Cretaceous; and the Subcarboniferous occurs along the eastern portion of the Carboniferous area. It includes about 175 feet (maximum thickness) of Kinderhook beds, consisting of alternating strata of sandstone and limestone, the latter partly magnesian; 190 feet of Burlington limestone, in which are some siliceous beds; 50 feet of Keokuk limestone, well developed about Keokuk; 75 feet of St. Louis limestone, having magnesian limestone below, next a gray friable sandstone, and above gray limestone. The Kinderhook beds reach farthest north; the Burlington and Keokuk, much less so; the St. Louis, nearly to the limit of the Kinderhook. The Chester group is not present, the Coal-measures resting directly on the St. Louis limestone.

In Missouri, the whole thickness of the Subcarboniferous limestone is 1,150 feet.

In Kentucky and Tennessee, the subdivisions of the Subcarboniferous formation observed in Illinois are not distinct. In Middle Tennessee, according to Safford, there are two groups. The lower is the *Siliceous group*, consisting, commencing below, of (1) the Protean beds, cherty and argillaceous beds, with some limestone, 250 to 300 feet, and (2) the Lithostrotion or Coral beds, an impure cherty limestone, the equivalent of the St. Louis limestone, about 250 feet thick. The upper member is *limestone*, 400 feet thick on the northern borders of the State, and 720 on the southern. These two divisions occur also in East Tennessee.

The Upper member also extends into the northeast corner of Mississippi, where it is overlaid by Cretaceous beds (Hilgard). At Huntsville, Ala., Worthen found it to consist principally of gray limestones, partly oölitic, partly cherty, with some shaly beds, in all about 900 feet. The larger portion of the series yields Chester fossils; but characteristic forms of the St. Louis group mark the age of the lowest 250 to 300 feet.

The Michigan Carboniferous area appears to have been an independent basin, at the time of the formation of the rocks. There are four groups of strata, according to Winchell: the first, or lowest, 173 feet of grits and sandstones, which he has called the *Marshall Group;* the second, 123 feet of shales and sandstones, called the *Napoleon Group;* the third, 184 feet of shales and marlyte, with some limestone and gypsum, called the *Michigan Salt-group;* the fourth, the Carboniferous limestone, sixty-six feet thick. This limestone is well exposed at Grand Rapids.

In Ohio, the chief part of the Subcarboniferous is the Waverley sandstone, 640 feet thick on the Ohio River, bearing evidences of shallow-water origin, and containing, 130 feet above its base, a black shale sixteen feet thick; going northward, the middle portion is a conglomerate. Above the sandstone, there is in some places a limestone ten to twenty feet thick, of the age, according to Meek, of the Chester and St. Louis groups. It was first found by E. B. Andrews. It is a magnesian limestone, and occurs in Muskingum, Perry, Hocking, Vinton, Jackson, and Scioto counties.

(*b.*) *Appalachian region.* — In Pennsylvania, two groups are recognized by H. D. Rogers, the *lower* called by him the Vespertine series, and the *upper* the Umbral series. It is probable that these divisions are equivalents of those in Tennessee. The rocks of the *lower* group are, in the main, coarse grayish conglomerates and sandstones; those of the *upper* group, soft shales, mostly of a red color. The *lower* group is 2,000 feet thick near Pottsville. Through much of the anthracite coal basin, it constitutes the encircling hills, as around the Wyoming basin, and in many places forms a grayish-white band, over another of red, the latter due to the Catskill beds, — the two thus making a red and white frame, as Lesley says, around the valleys or basins. It thins rapidly to the westward, the rock retaining its whitish color and siliceous character in Virginia. Sandstone beds alternate with the conglomerate; and, in New York, these finer layers abound in ripple-marks, and that oblique lamination (Fig. 61 *e*) which is due to contrary currents.

The shales of the *upper* group are soft, reddish, clayey beds, easily returning, on exposure, to mud, the original condition of the material. They alternate with sandstone layers, especially in the lower part. At Towanda, Blossburg, Ralston, Lockhaven, Portage Summit, etc., in upper Pennsylvania, the formation consists of two or three thick strata of shale, separated by as many strata, 50 to 200 feet thick, of greenish sandstone. (Lesley.) Some thin layers consist of an impure rough-looking limestone. This red-shale formation is 3,000 feet thick at the Lehigh, Schuylkill, and Susquehanna rivers; but on crossing the Coal-measures to the westward, it rapidly diminishes. At Broad Top, it is less than 1,000 feet; at the Alleghany Mountain, hardly 200; at Blairsville, 30 feet; and beyond, it is lost to view. (Lesley.) The soft shales retain still the ripple-marks from the ancient waves, and rain-drop impressions from the showers of the day. The Amphibian footprints described beyond are from this formation. To the southwest, in Laurel Hill and Chestnut Ridge, there is some impure limestone, along with red marlytes.

In West Virginia, Monongalia County, the Chester limestone has been recognized by Meek, six of its fossils being identical with Illinois species (Am. Jour. Sci., III. ii. 217). On the Potomac, at Westernport (W. B. Rogers), there are about eighty feet of impure limestone in the lower part of the formation, and 840 feet of overlying sandstone and shales. But, farther south and west, in Greenbrier Mountain, Pocahontas County, the formation thickens to over 2,000 feet, and includes 822 feet of limestone.

Seams of coal occur in the Subcarboniferous, at many places in Pennsylvania and Virginia. In Montgomery County, Virginia, there is a layer of coal, two to two and a half feet thick, resting on a bed of conglomerate; and, thirty to forty feet higher, there is another layer, six to nine feet thick, consisting of alternations of coal and slate. These coal-beds occur in the *Lower* group, and are covered by the shales of the Upper. In Pennsylvania, there is a coal-bed (and possibly two) in the same *Lower* group, at Tipton, at the head of the Juniata, 600 feet below the *Upper* shales; but, so far as known, it is a local deposit. (Lesley.) The Subcarboniferous coal deposits are sometimes called *false Coal-measures.*

(*c.*) *Eastern-border region.* — In Nova Scotia and New Brunswick, the Subcarboniferous rocks are, below, red sandstones, conglomerates, and red and green marlytes, of two groups: the *Horton* series, consisting of red sandstones, conglomerates, red and green marlytes; and, above these, the *Windsor* series, consisting of thick beds of limestones, full of fossils, with some red marlytes, and beds of gypsum, affording the gypsum exported from Nova Scotia and New Brunswick. Thus the upper part of the Subcarboniferous is the calcareous part, as in Ohio, Tennessee, and Western Virginia. The estimated thickness is 6,000 feet. To the north, toward the Archæan, the limestones fail; and, instead, the rocks are to a greater extent a coarse conglomerate. To the south, limestones prevail. The localities of these beds, mentioned by Dawson, are the Carboniferous districts of northern Cumberland, Pictou, Colchester, and Hants, Richmond County and southern Inverness, Victoria, and Cape Breton. The best exposures of the lower or Horton series are at Horton Bluff, Hillsborough, and other places in southern New Brunswick.

In the lower part of these Subcarboniferous beds, as in those of Virginia, there are, on a small scale, "*false*" *Coal measures*, and, in one instance, a bed of *erect trees*, under-clays, and thin coal seams; and the same beds contain numerous remains of fishes. The fish-bearing shales of Albert Mine, New Brunswick, are of this period. (Dawson.) This mine affords a peculiar coaly material, pitch-like in aspect, which has been named *Albertite;* it fills a fissure, instead of constituting a true coal-bed.

(*f.*) *Rocky-Mountain and Pacific-border regions.* — Over large portions of these regions, the limestones of the Subcarboniferous have not been distinguished from those of the following epoch. In most cases, their recognition only waits for the more careful study of the fossils; but, at some points, they appear to be really wanting. They have been identified in the Elk Mountains, and other ranges of the crest chain of the mountains in western Colorado; on the eastern slopes of the Wind River Mountains, in Wyoming. In Montana, at "Old Baldy," near Virginia City, there are fossils of the Chester group, and probably the Lower Subcarboniferous beds are also present. (Meek.) In Idaho, near Fort Hall, Bradley found masses of limestone filled with minute shells, many species of which Meek has identified with forms characteristic of the oölitic beds of the St. Louis group, at Spergen Hill, Indiana. In Utah, the same beds occur in the limestones which surround the silver mines of the Wahsatch and Oquirrh ranges. From the latter range, near Lake Utah, a species of *Archimedes* has been reported. The Carboniferous limestones reported from the Humboldt and other ranges of the Great Basin, doubtless include beds properly referable to the Subcarboniferous, though G. K. Gilbert reports that, over the southern portion of this area, he has been unable to separate them from the beds including typical Coal-measure fossils. In northern California, the Subcarboniferous occurs in the Gray Mountains near Bass's Ranch, and at Pence's, eighty miles farther south. In the Gray Mountains, the limestone is 1,000 feet thick, forming part of the auriferous series, and is doubtingly referred by Meek to the St. Louis horizon.

II. Life.

1. *Plants.*

The sea-weeds included the *Spirophyton*, which first appeared under the species *S. cauda-galli*, in the Lower Devonian, and characterized the Cauda-galli grit (p. 254): it is found in the sandstone of Ohio.

The terrestrial vegetation of the Subcarboniferous period was very similar to that of the lower part of the Carboniferous. There were Lycopods, of the tribes of *Lepidodrendon* and *Sigillaria*, and various *Ferns*, *Conifers*, and *Calamites*. The vegetation may have been as

profuse for the amount of land, although the circumstances were less favorable for its growth and accumulation in marshes, — the essential prerequisite for the formation of large beds of coal.

In the Subcarboniferous of Pennsylvania occur, according to Lesquereux, *Cyclopteris obtusa* Lsqx (also found in the Catskill group of the Upper Devonian), *C. Bockschiana* Göpp., remains of *Lepidodendra* and *Stigmaria minuta* Lsqx.; also, in Illinois, the Tree-fern *Megaphytum protuberans* Lsqx., *Caulopteris Worthenii* Lsqx., *Lepidodendron costatum* Lsqx., *L. turbinatum* Lsqx., *L. obscurum* Lsqx., *L. Veltheimianum* Sternb., *L. Worthianum* Lsqx., *Stigmaria anabathra* Corda, *S. minor* Göpp., *S. umbonata* Lsqx., and others; *Calamites Suckowii* Brngt., *Knorria imbricata* Sternb., all from the Chester group.

In the Chester group sandstones of Indiana, according to Collett, occur *Stigmaria*, *Lepidodendron aculeatum*, *L. diplotegioides* Lsqx., *L. forulatum* Lsqx., *Lepidostrobus*, *Knorria*, *Hymenophyllites Clarkii* Lsqx., *Cordaites borassifolia*, *Neuropteris dilatata* Lsqx., *N. rarinervis* Lsqx., *Alethopteris Owenii* Lsqx., *Callipteris Sullivantii* Lsqx., etc. One specimen of *Lepidodendron* had portions of the leaves attached to the stem, and twelve to fourteen inches long, though only from one-eighth to one-fourth of an inch in width.

In the Subcarboniferous of Nova Scotia and New Brunswick, Dawson has made out the following species: Ferns, *Cyclopteris Acadica* Dn., and another species supposed to be a *Hymenophyllites*; Lycopods: *Lepidodendron corrugatum* Dn., *L. Sternbergii* Brngt., *L. tetragonum* Sternb., *L. aculeatum* Sternb., *Lycopodites plumula* Dn.; also *Stigmaria ficoides* Brngt., *Cordaites borassifolia* Ung.

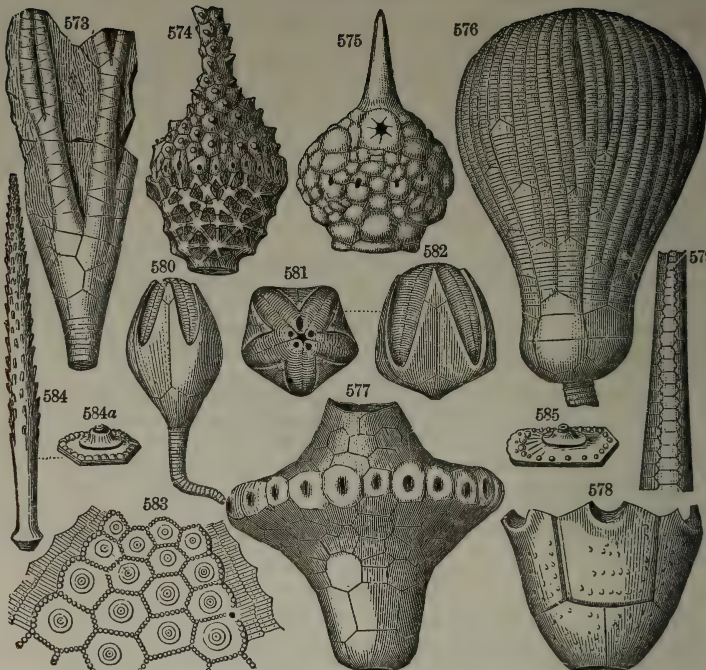
Of the above, the *Stigmariæ*, *Calamites*, *Cordaites*, and *Lepidodendron Worthianum* occur higher in the series, the *Calamites* and *Cordaites* continuing even into the Upper Coal-measures.

2. *Animals.*

The animal life was remarkable for the great profusion and diversity of Crinoids, — or Sea-lilies, as they are sometimes called. Some of the Crinoids — mutilated of their rays or arms, as is usual with these fragile species, except when buried in shales — are represented in Figs. 573–582. The period might well be called the Crinoidal period in geological history. Among the kinds, the *Pentremites* (Figs. 580–582) are perhaps the most characteristic. Instead of having a circle of arms, like most Crinoids, the summit is closed up, so as to look like a bud (whence the name Blastids, applied to the family, from the Greek βλαστός, *a bud*); and the delicate jointed tentacles are arranged in vertical lines along the pseudo-ambulacral areas.

There were also other Echinoderms, related to the modern *Echinus*, but peculiar in the large number of vertical series of plates of which the shell consists. One species is represented in Fig. 586, but one half the natural size. The vertical series of plates in the ambulacral series, which are indistinct in this figure, are shown, enlarged, from another species, in Fig. 587 *b*. Fig. 587 represents a top view, and 587 *a* a portion of the lateral, of still another of these ancient Echinoids. A true Polyp-Coral, eminently characteristic of the period, is the *Lithostrotion Canadense* (Figs. 588, *a*). It is a columnar coral, having a conical elevation at the bottom of each of the cells, and grows often to a very large size.

Figs. 573–585.

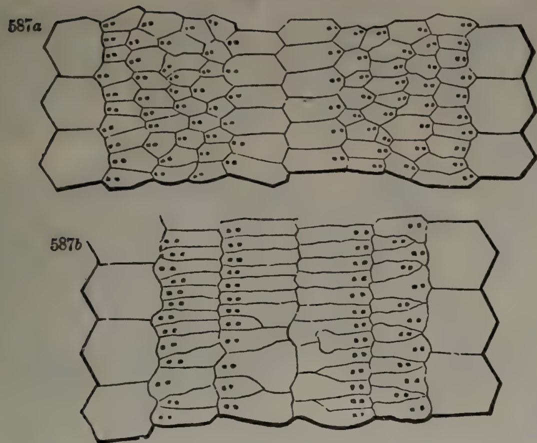


ECHINODERMS.—Fig 573, Poteriocrinus Missouriensis; 574, Actinocrinus proboscidialis; 575, Dorycrinus unicornis; 576, Zeacrinus elegans; 577, Batocrinus Christyi; 578, Platycrinus Saffordi; 579, the proboscis of Batocrinus longirostris; 580, Pentremites pyriformis; 581, 582, P. Godonii (florealis); 583, Archæocidaris Wortheni; 584, 584 *a*, A. Shumardana; 585, A. Norwoodi.

Figs. 586–587.

ECHINOIDS.—Fig. 586, Oligoporus nobilis (× ½); 587, Melonites multipora, view of top (× 2).

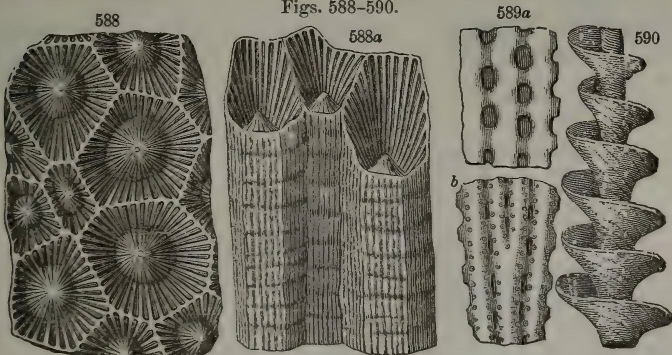
Figs. 587 *a*, *b*.



ECHINOIDS. — Fig. 587 *a*, Melonites multipora (× 2), side view, showing a portion of one of the ambulacral series of plates; 587 *b*, Oligoporus Danæ (× 2), id.

Among Mollusks, there were the coral-making, auger-shaped Retepores, called *Archimedes*, belonging to the order of Bryozoans. The cells, in which the animals were, are represented of natural size, in

Figs. 588–590.

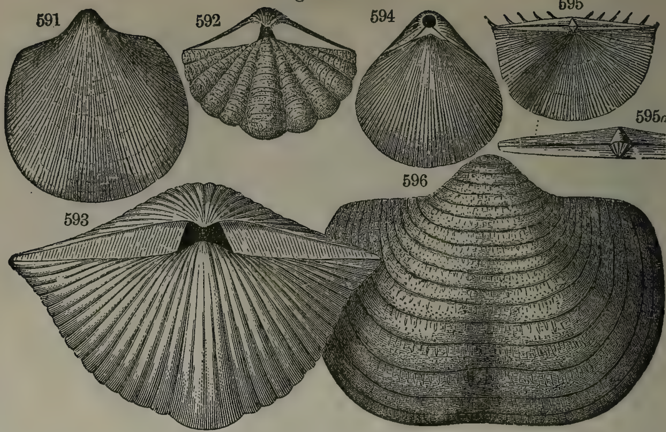


POLYP-CORAL. — Fig. 588, Portion of the Coral, Lithostrotion Canadense; 588 *a*, vertical view of the same. BRYOZOAN. — Figs. 589 *a*, *b*, 590, Archimedes Wortheni.

Fig. 589 *b*, showing a portion of the under surface of the expanded frond of the screw-shaped coral.

Besides these, Brachiopods were numerous, especially of the genera *Spirifer* and *Productus*. One of the *Spirifers* is represented in Fig. 593, and a common *Productus* in Fig. 596; another *Spirifer* in Fig.

Figs. 591–596.



Brachiopods. — Fig. 591, Orthis Michelini, var. Burlingtonensis; 592, Spiriferina octoplicata; 593, Spirifer bisulcatus; 594, Retzia Verneuiliana; 595 *a*, Chonetes variolata; 596, Productus punctatus.

597, and straight-hinged species allied to *Productus* (of the genus *Chonetes*), in Figs. 595, 598.

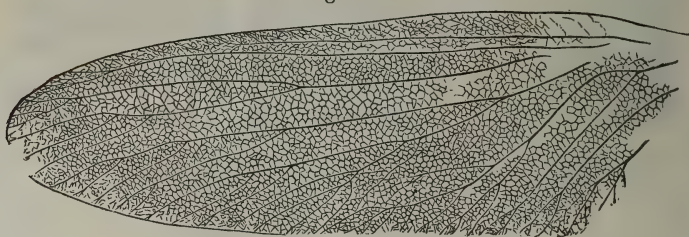
Figs. 597, 598.

Fig. 597, Spirifer biplicatus; 598, 598 *a*, Chonetes ornata.

There were also many Cephalopods, of the genera *Goniatites* and *Nautilus*, and a few of the *Orthoceras* family.

Among Articulates, Trilobites, so abundant in earlier time, were rare fossils. There must have been Insects of various kinds. Fig. 599 represents a wing found near Paoli, Indiana; the insect was one of the four-winged kinds

Fig. 599.

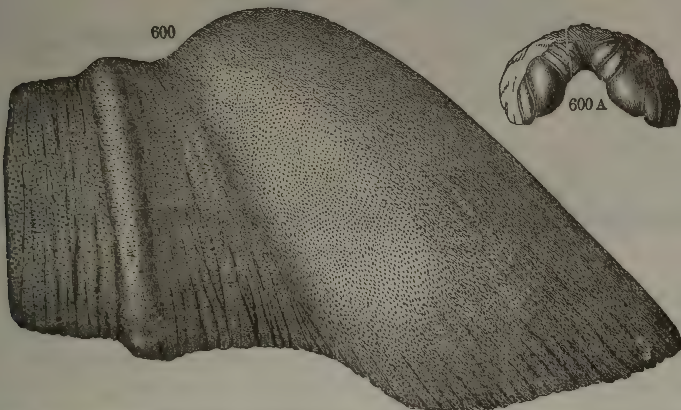


Wing of a Neuropter. — Paolia vetusta ($\times \frac{3}{2}$).

having net-veined wings — that is, a Neuropter; but differed in the character of the veining from ordinary May-flies, and other modern kinds of the tribe.

Under Vertebrates, there were both *Fishes* and *Amphibians.* The Fishes were either Ganoids or Selachians; and the latter embraced large numbers of the Cestraciont kind, having great bony plates in the mouth, for mastication. Fig. 600 represents, natural size, one from a large species, of the genus *Cochliodus*, from Illinois. The posi-

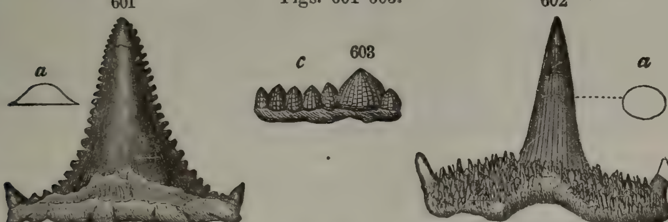
Figs. 600, 600 A



TEETH OF CESTRACIONT SHARKS. — Fig. 600, Cochliodus nobilis; 600 A, C. contortus (× ⅓).

tion in the mouth is shown in Fig. 600 A, representing, one third the natural size, the jaw of a foreign species. The teeth of other sharks, called *Hybodonts*, are shown in Figs. 601 to 603. These also

Figs. 601–603.



TEETH OF SHARKS. — Fig. 601, Carcharopsis Wortheni; 602, Cladodus spinosus; 603, Orodus mammillaris.

were numerous. Large fin-spines of some of the Sharks have been found in the rocks, one of them eight inches long.

Footprints of Amphibians have been found at a few localities in American Subcarboniferous rocks. A reduced view of a slab from near Pottsville, Pennsylvania, is shown in Fig. 604. There is a succession of six steps, along a surface little over five feet long: each step is a double one, as the hind-feet trod nearly in the impressions

of the fore-feet. The print of the fore-feet is something like that of a hand with five stout fingers, the whole four inches broad; that of the

Fig. 604.

Tracks of Sauropus primævus (× ⅛).

hind-foot is similar, but somewhat smaller, and four-fingered. The Amphibian was therefore large; this is also evident from the length of the stride, which was thirteen inches, and the breadth between the outer edges of the footprints, eight inches. There is also a distinct impression of a tail, an inch or more wide. The slab is crossed by a few distant ripple-marks (eight or nine inches apart), which are partially obliterated by the tread. The whole surface, including the footprints, is covered throughout with rain-drop impressions.

We thus learn that there existed, in the region about Pottsville, at that time, a mud-flat on the border of a body of water; that the flat was swept by wavelets, leaving ripple-marks; that the ripples were still fresh when a large Amphibian walked across the place; that a brief shower of rain followed, dotting with its drops the half-dried mud; that the waters again flowed over the flat, making new deposits of detritus, and so buried the records.

Characteristic Species.

1. Protozoans. — Although the class of *Rhizopods* probably commenced in the lowest Silurian, the earliest described species from an American rock is the *Rotalia Baileyi* H., from the St. Louis limestone of Indiana.

Sponges. — The hornstone of the Subcarboniferous limestones of Illinois and Indiana abounds in microscopic spicula of sponges, along with a few Desmids similar in general to those of the Corniferous limestone (p. 257). (M. C. White.) *Palæacis* (*Sphenopoterium*) *obtusa* M. & W., from the Keokuk beds; *P. cuneata* M. & W., from the St. Louis limestone.

2. Radiates. — (*a.*) *Polyps.* — Figs. 588, *a*, *Lithostrotion Canadense* Castelneau (*L. mamillare* of some authors, — among whom Milne Edwards, after thus naming it, makes a correction in a note), from the St. Louis limestone.

(*b.*) *Echinoderms; Crinoids.* — Fig. 580, *Pentremites pyriformis* Say; Figs. 581, 582,

P. Godonii Defr. (*P. florealis*, in part), — both from the Kaskaskia limestone; *P. Woodmani* M. & W. Fig. 573, *Poteriocrinus Missouriensis* Shumard, from the St. Louis limestone; Fig. 574, *Actinocrinus proboscidialis* H.; Fig. 575, *Dorycrinus unicornis* M. & W.; Fig. 576, *Zeacrinus elegans* H., — this and the two preceding from the Burlington limestone; Fig. 577, *Batocrinus Christyi* M. & W., the arms fallen off, — from the Encrinal limestone of Missouri; Fig. 579, proboscis of *Batocrinus longirostris* H.; Fig. 578, *Platycrinus Saffordi* Troost, side-view, from Burlington. Most of the above Crinoids have lost their arms and pedicels. The most prolific locality of Crinoids, as yet known, is Burlington, Iowa, where Mr. Charles Wachsmuth has collected three hundred and fifty-five species, representing forty-four genera, besides six Echinoids, four Asterioids, and one Ophiuroid. The Keokuk beds of Crawfordsville, Indiana, yield much more numerous specimens, and in more nearly perfect condition; but less than fifty species have yet been found there. The genera most numerously represented are *Actinocrinus* (including several subgenera), *Cyathocrinus*, *Dichocrinus*, *Forbesiocrinus*, *Platycrinus*, *Poteriocrinus*, *Scaphiocrinus*, and *Zeacrinus*.

Echinoids. — Fig. 583, *Archæocidaris Wortheni* H., of the St. Louis limestone; Fig. 584, *A. Shumardana* H., of the St. Louis limestone, — a spine enlarged; Fig. 584 *a*, plate of the same species, enlarged about two diameters; Fig. 585, plate of *Archæocidaris Norwoodi* H., natural size, from the Chester limestone. Fig. 587, *Melonites multipora* O. & N., from the St. Louis limestone, the apical disc; 587 *a*, a portion of one of the ambulacral series, enlarged two diameters; Fig. 586, *Oligoporus nobilis* M. &. W., half natural size, from the Burlington limestone; Fig. 587 *b*, ambulacral plates of *O. Danæ* M. & W., enlarged two diameters. Figures 586, 587, *a*, *b*, are from Worthen's Report on the Geology and Paleontology of Illinois. The genus *Archæocidaris*, like the modern *Cidaris*, has large prominences on the plates, to support the spines, which are also large. In *Melonites* and *Palæechinus*, the plates are without prominences, and the spines small.

3. Mollusks. — (*a.*) *Bryozoans.* — Fig. 590, *Archimedes Wortheni* H., being a portion of the spiral axis, with the reticulated expansion removed. Fig. 589 *a*, a portion of the reticulated expansion, magnified and showing the non-poriferous surface. Fig. 589 *b*, the poriferous side of the same.

(*b.*) *Brachiopods.* — Fig. 598, *Chonetes ornata* Shum. (natural size), from the Lithographic and Chouteau limestones, Missouri; 598 *a*, enlarged surface-markings of same; Fig. 597, *Spirifer biplicatus* H., from Burlington and Quincy, Illinois: *Sp. Keokuk* H., from the Keokuk beds; Fig. 591, *Orthis Michelini* Morr. (var. *Burlingtonensis* H.), from the Burlington limestone; *Hemipronites crenistria* Dav. (*Orthis* or *Streptorhynchus umbraculum*) (Fig. 605); Fig. 592, *Spiriferina octoplicata* M.; Fig. 593, *Spirifer bisulcatus* Sow. (*increbescens* H.); Fig. 594, *Retzia Verneuiliana* H.; Fig. 595, *Chonetes variolata* D'Orb.; Fig. 595 *a*, hinge-line of same, and aperture, closed by a pseudo-deltidium; Fig. 596, *Productus punctatus* Mart.; also *P. Flemingii* Sow., *P. elegans* N. & P., *Spirifer incrassatus* Eichw., *Sp. spinosus* N. & P., from the Chester limestone, etc. The *Spirifer incrassatus* is confined in Missouri to the lower Archimedes limestone. Many of the other Brachiopods occur not only in the Subcarboniferous, but also in the Coal-measures. They are common also in Europe.

(*c.*) *Lamellibranchs.* — *Nucula Shumardana* H., *N. nasuta* H., *Cypricardina Indianensis* M., *Conocardium Meekanum* H., all from the St. Louis limestone of Indiana, Illinois, and Idaho; *Pinna Missouriensis* Swallow, of the Chester limestone of Illinois; species of *Yoldia*, *Nuculana*, *Myalina*, *Schizodus*, *Aviculopecten*.

(*d.*) *Pteropods.* — Species of *Bellerophon*, *Conularia*, etc.

(*e.*) *Gasteropods.* — *Euomphalus Spergenensis* H., *Pleurotomaria Meekana* H., and many other species of these genera, as well as *Platyceras*, *Straparollus*, *Naticopsis*, *Natica*, *Bulimella*, *Loxonema*, etc.

(*f.*) *Cephalopods.* — The Cephalopods are of the genera *Nautilus* (*N. spectabilis* M. & W., from the Chester, two feet in diameter), *Orthoceras* (*O. nobile* M. & W., from the Chester, five to six feet long and one foot in diameter), *Gyroceras* (*G. Burlingtonense* H., from Iowa, five inches in diameter), *Goniatites*, etc.

4. Articulates. — Trilobites, of the genus *Phillipsia*, and Ostracoids, of the genera *Cythere*, *Beyrichia*. A bed of limestone, four feet thick, north of Pella, Iowa, is mostly made up of shells of a *Beyrichia*. The Crustaceans allied to *Ceratiocaris*, from the top of the "Black Slate," in Kentucky (p. 267), though referred to the Devonian, may possibly belong rather to the Subcarboniferous.

The Insect, *Paolia vetusta* Smith (Fig. 599), is from the whetstone beds of Orange County, Indiana, which have also yielded large numbers of tracks of Insects and Crustaceans, with some trails of Mollusks. These beds are of the age of the Chester group.

5. Vertebrates. — *Fishes.* — The species of American Subcarboniferous Fishes have been described mainly by Newberry, and Newberry & Worthen. They include Hybodont Selachians, of the genera *Diplodus*, *Carcharopsis*; of Cestracionts, of the genera *Orodus*, *Helodus*, *Cochliodus*, *Sandalodus*, *Psammodus*, *Deltodus*, *Cladodus*, etc.; and Petalodonts, of the genera *Petalodus*, *Petalorhynchus*, *Antliodus*, *Chomatodus*, etc., besides spines of the genera *Leptacanthus*, *Ctenacanthus*, *Homacanthus*, *Drepanacanthus*, *Gyracanthus*. The species described by Newberry & Worthen, from Illinois specimens, are sixteen of Hybodonts, twenty-six of Petalodonts, and fifty-two of Cestracionts, with nine of fin-spines. Fig. 600, tooth of *Cochliodus nobilis* N. & W., from Illinois. Fig. 602, *Cladodus spinosus* N. & W., from the St. Louis limestone, Missouri; *a*, section of the same; Fig. 601, *Carcharopsis Wortheni* Newb., from Huntsville, Ala.; Fig. 603, *Orodus mammillaris* N. & W., from the Warsaw limestone, Warsaw, Illinois.

Amphibians. — Fig. 604, tracks of *Sauropus primævus* Lea, one-eighth natural size, discovered near Pottsville, Pa., by Isaac Lea, who has published a memoir upon them in large folio, with a full-sized engraving of the slab.

The Subcarboniferous limestones of Nova Scotia and New Brunswick contain some fossils that ally the fauna more with the European than with that of the Interior Continental basin of North America. Among them are the *Spirifer glaber* Sow. (Fig. 554) and *Productus Martini* Sow., both of which are European species.

III. General Observations.

Geography. — As, in the first half of the Upper Silurian, there was a period — the Niagara — when a sea, profuse in life, and thereby making limestones, covered a large part of the Interior Continental basin; and again, in the early part of the Devonian age, — the Corniferous period, — the same conditions were repeated; so, in the early Carboniferous, there was a similar clear and open mediterranean sea, and limestones were forming from the relics of its abundant population. In the period of the Upper Silurian referred to, the living species were of a miscellaneous character, Brachiopods, Crinoids, and Corals occurring in nearly equal proportions; but in that of the Devonian, Corals were greatly predominant, and in that of the Carboniferous, Crinoids had as remarkable a preëminence. By an open sea is meant one having free connection in some part with the ocean; and this connection must have been on the south, toward the Mexican Gulf; for the arenaceous deposits of the wide Appalachian region show that the opening eastward into the Atlantic was for the most part imperfect. The mediterranean sea alluded to was, in fact, only an extension northward of the Mexican Gulf.

As the Subcarboniferous period opened, the conditions of the Later

Devonian still lingered; and fragmental deposits, either clayey or sandy, were made over the Mississippi region, as well as to the eastward. With its progress, the crinoidal sea increased in depth and in freedom from sediments; yet these continued, at intervals, through the formation of the Kinderhook beds, though to a less extent in Missouri than farther north. The earthy depositions then became less frequent, the rock of the Burlington and Keokuk group being mainly limestone; but, at the same time, as remarked by Hall, the northern border of the Interior sea had moved southward, the northern limit of the Burlington limestone being two hundred miles farther south than that of the earlier beds, and that of the Keokuk and St. Louis group still farther south. This limestone-making sea, though gradually deepening in the valley, did not entirely preserve its freedom from sediments, far east of Illinois; for even central Tennessee and Ohio, as well as the Appalachian region, was contemporaneously a region of accumulating sand and gravel beds, and probably for the most part one of shallow waters. During the progress of the St. Louis epoch, the sea deepened in Tennessee, and some limestones were made, from Crinoids and shells; and moreover, according to C. A. White, it extended northward, in Iowa, nearly to the limit of the Kinderhook group. Afterward, there was again a contraction on the north, the Chester limestones reaching only to Alton, Illinois; but in other directions the sea had then greatly widened limits and increased depth, the limestone spreading to the southward, through Tennessee and Kentucky to West Virginia, Alabama, and Mississippi, and being represented by thin beds in Ohio and western Pennsylvania. In the Appalachian region, there were not only fragmental beds, but a very great thickness of them, the thickness increasing from the New York boundary on the north and from western Pennsylvania on the west, toward the region of Pottsville, where the whole was 4,000 to 5,000 feet, proof that, along the central portions of the region, there was this amount of subsidence during the period, and that the State of New York on the north did not participate in it, as it had done in the preceding Catskill period. This thickness of Subcarboniferous rocks is four times that in the Mississippi valley.

The region of the Cincinnati geanticlinal, from Lake Erie into Kentucky, was, as stated by Newberry, a peninsula during the era.

Michigan was to some extent independent in its movements, and yet there, as elsewhere, the latter part of the period was the time of limestone-making, and therefore of clearer waters. This was true also of the Carboniferous region of Nova Scotia and New Brunswick, where the beds are mainly fragmental.

The chert, which abounds in some of the beds, probably has the

same infusorial origin as that of other formations (p. 257); and so also the quartz constituting the geodes. Beyond this, the origin of the geodes has not been explained.

2. Foreign Subcarboniferous.

The Subcarboniferous period was a time of limestone-making also in Britain and Europe. There is proof, therefore, of a wide extension of those geographical conditions that characterized America, — that is, of an extensive submergence of the continental lands, as a prelude to the period of emergence and terrestrial vegetation that followed. Moreover, the later part of the series is most purely limestone, the earlier in many places consisting of shale or sandstone. The limestone is often called the "Mountain limestone."

In Great Britain, the limestone occurs in portions of South and North Wales, and near Bristol, 500 to 1,500 feet thick; in Derbyshire and North Straffordshire, in central England, 1,000 to 4,000 feet; in Cumberland, in Northern England, 1,000 to 1,500 feet; along the midland counties of Scotland, but of little thickness compared with that in England; in Ireland, with a thickness of 3,000 feet or more.

There is more or less of shale or sandstone in the limestone formation of these regions. In Wales, the limestone is underlaid by 200 to 300 feet of Subcarboniferous shale, and in Ireland, by 500 to 5,000 feet of shale and sandstone. The series in southern Ireland includes 2,000 feet of Subcarboniferous shale, resting on 3,000 feet of grit called the Coomhola grit, and that on reddish Devonian sandstones; and that of northern Ireland consists of (1) 500 feet of yellow sandstone, and (2) 2,700 feet of limestone, with some intercalcated shale and sandstone. The Coomhola grit is referred by some geologists to the Devonian; but it includes nearly the same fossil shells as the slate above, along with abundance of *Spirifer disjunctus*, *Spirifer cuspidatus*, and other Subcarboniferous forms.

In Belgium, near Liége, there are, at base, shales and sandstone overlaid by Crinoidal limestone, partly cherty; together they constitute the *Condrusian* system of Dumont.

Over Russia — a great Interior Continental region like that of North America — the Subcarboniferous rocks are mainly limestone, and have a wide distribution. The formation is well displayed, according to Murchison, on the western flank of the Ural Mountains, upturned, and overlying the Devonian, and along parts of the Volga. Near Moscow, it has been reached by boring through the Jurassic and Coal-measures.

In the Subcarboniferous limestone of Great Britain, there are beds of trap and other igneous rocks. In Durham and Northumberland, the interstratified sheets of basaltic rock extend for miles. In Scotland, the interpolations of trap, porphyryte, and tufas are numerous, and occur throughout the series, especially its lower part. They form a conspicuous chain of terraced heights, from near Stirling, through the range of the Campsie, Kilpatrick, and Renfrewshire hills, to the banks of the Irvine in Ayrshire, and thence westward by the Cumbrae Islands and Bute to the south of Arran. (Geikie.) In Ireland, county of Limerick, there are masses of trap 1,200 to 1,300 feet thick, with tufaceous beds, intercalated with the limestone strata.

Life.

Plants. — Small coal-beds and a number of species of coal-plants occur in the strata. The plants are related to those of the lower part of the Coal-measures, and are, for the most part, the same in species.

At Moresnet, near Aix, in shales under the Subcarboniferous limestone, has been found *Cyclopteris Rœmeriana* Göpp., with *Spirifer disjunctus* Sow. A number of species have been obtained in the Vosges, among them *Calamites radiatus* Brngt., *Lepidodendra*, *Knorriæ*, *Stigmariæ*. Heer has designated the horizon of these plants, the *Ursa* stage. He refers to it the species from Bear Island, mentioned on page 283, and also includes the species from the Yellow sandstone of Ireland, which underlies the Subcarboniferous slate and limestone, as stated on the same page.

Animals. — The "Mountain limestone," like the American beds, is noted for its Crinoids; its Brachiopods, of the genera *Productus* and *Spirifer;* its Corals, of the genus *Lithostrotion;* its Ganoid Fishes and Sharks; its few Amphibian relics; and also for the absence of Trilobites of all the old genera. There are also various Rhizopods; and, among them, the kind called *Fusulina* (Fig. 646, p. 332) is especially interesting on account of its wide distribution, and its being exclusively a Carboniferous type; it is common in the Upper beds in Russia, the Southern Alps, Armenia, and Spain; also the Carboniferous beds of North America, but not the Subcarboniferous.

Characteristic Species.

Among *Rhizopods*, the limestone in northern England contains aggregations of the spheroidal species, *Saccammina Carteri* Brady, occurring as groups of single isolated spheroids, or occasionally of strings of them, the diameter of each averaging an eighth

Figs. 605–607.

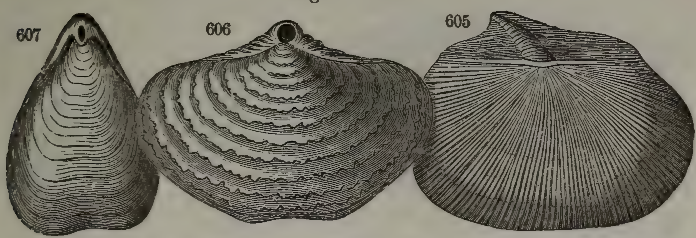


Fig. 605, Hemipronites crenistria; 606, Spirigera lamellosa; 607, Terebratula hastata.

Figs. 608–610.

Fig. 608, Productus longispinus; 609, Spirifer glaber; 610, Nautilus (Trematodiscus) Koninckii.

of an inch, though rarely a fifth of an inch, a remarkable size for this class. They lie so closely together, that a mass seems to be made up of them. It is very abundant in the "four-fathom" limestone of the English Subcarboniferous. The only other species

of the genus thus far described is the *Saccammina sphærica* Sars, a species now living over the bed of the northern Atlantic, off Norway. *Fusulina cylindrica* Vern. occurs in Russia, Spain, etc.; *F. robusta* M., in Russia, Southern Alps, Armenia: neither species has been found in Great Britain.

Among Mollusks: Fig. 605, *Hemipronites* (formerly *Streptorhynchus* or *Orthis umbraculum*) *crenistria*, common in the American Carboniferous; Fig. 606, *Spirigera* (*Athyris*) *lamellosa* Dav.; Fig. 607, *Terebratula hastata* Sow.; Fig. 608, *Productus longispinus* Sow., *P. scabriculus* Sow.; Fig. 609, *Spirifer glaber* Sow., *S. speciosus* Br, S. *cuspidatus* Sow., *S. disjunctus* Sow.; *Chonetes Dalmaniana* Kon.; *Orthis Michelini* Morr., *O. resupinata* Phill. *Pleurotomaria carinata* Sow. retains its original colored markings, as first observed by the late Professor Forbes; this author hence inferred that it was a shallow-water species, but it is now known that colored species occur at a great depth in the ocean. Fig. 610, *Nautilus* (*Trematodiscus*) *Koninckii* D'Orb.

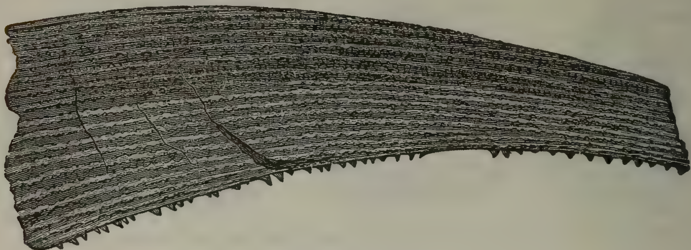
Fig. 611.

Phillipsia seminifera.

Trilobites occur, of the only three Carboniferous genera, *Phillipsia*, *Griffithides*, and *Brachymetopus*. Fig. 611, *Phillipsia seminifera* Morr.: *P. pustulata* Kon. occurs in the Irish rocks.

Remains of fishes are very common in Europe and Britain. Among Cestracionts (or sharks with pavement-teeth), *Cochliodus contortus* Ag., Fig. 600 A; among Hybodonts (or sharks with regular teeth, the teeth with obtuse or rounded edges), *Cladodus marginatus* Ag. Fig. 612, part of the fin-spine, *Ctenacanthus major* Ag.; one specimen has a length of *fourteen and a half inches*, and was probably eighteen inches in the living Cestraciont. The old fishes, as Agassiz observes, must have had gigantic dimensions. Another spine, *Oracanthus Milleri* Ag., is nine and a half inches long and three inches wide at base; and yet it has lost some inches at its extremities. These species and many other remains of fishes are found in fish-bone beds in the limestone at Bristol, England, and at Armagh, Ireland.

Fig. 612.



Part of a spine of Ctenacanthus major.

3 Disturbances Preceding the Carboniferous Period.

It has been stated, on page 290, that the Coal-measures, in parts of northern and western Illinois, rest on tilted Silurian strata; and the fact is illustrated by a section from La Salle County. Another section, published by Hall, is shown in the annexed figure; it represents the Coal-measures (A), in Rock Island County, at Port Byron, overlying upturned Niagara beds (B). Like that of La Salle

Fig. 612 A.

County, it gives no good reason for concluding that the upturn of the Silurian formation took place *directly before* the era of the Coal-measures; but simply teaches that the disturbance occurred at some time between the Niagara period, in the Upper Silurian, and the Carboniferous period. A geographical change, however, occurred in the region of the Upper Mississippi, as remarked upon by Hall, which gave the Coal-measures a northern extension beyond the Chester limestone, the last of the Subcarboniferous, and even beyond the Kinderhook beds; and thus was produced an overlapping of the latter by the former, instead of perfect conformability. Hall says, in his Report on Iowa (1858), "I have ascertained, in the most satisfactory manner, that the coal-fields of Iowa, Missouri, and Illinois rest unconformably upon the strata beneath, whether these strata be Carboniferous limestones, Devonian, Upper Silurian, or Lower Silurian rocks." As unconformability by overlap is all that is certainly known to occur between the Coal-measures and the Subcarboniferous formation, this was apparently the foundation for including this formation in the above general statement.

In Great Britain, Russia, and the most of Europe, the Carboniferous and Subcarboniferous beds, when occurring together, are conformable. But, in central and southern France, as Murchison says, the two are *always unconformable.* In Bavaria also, at Hof, the Subcarboniferous limestones and Devonian follow one another regularly, though inclined together at a large angle; while the Coal-measures of Bohemia lie in horizontal strata, over their tilted edges.

2. CARBONIFEROUS PERIOD (14).

1. Distribution of the Carboniferous Rocks.

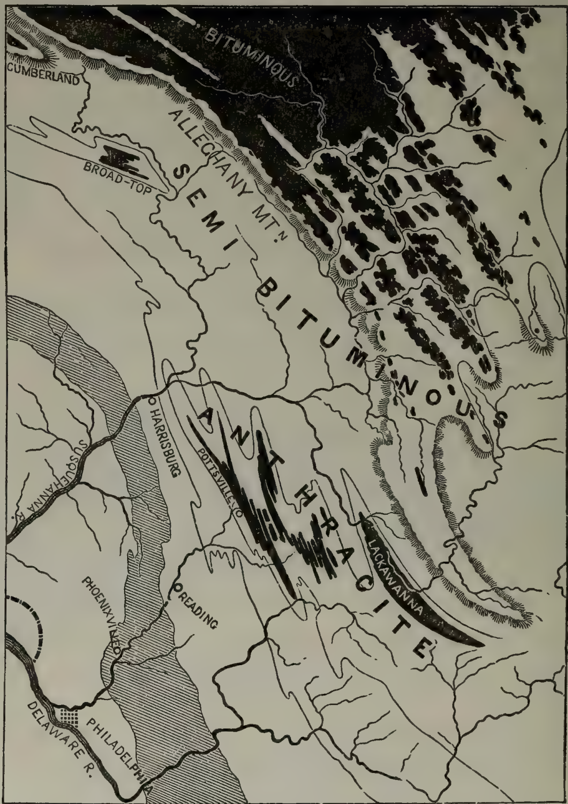
The areas of Carboniferous rocks, and of the Coal fields of North America, have been pointed out on page 291, and also on the map on page 292.

The principal coal-producing fields are (1) the *Appalachian;* (2) the *Eastern Interior*, or that of Illinois and the adjoining States; (3) the *Western Interior*, or that of Missouri and the States adjoining on the north, west, and south, and reaching, though with some interruptions, into Texas; (4) the *Michigan*; (5) the *Rhode Island*; (6) the *Acadian*, or that of Nova Scotia and New Brunswick.

The thickness of the Coal-measure rocks in these regions varies from 100 to 1,000 feet in the Interior coal areas, to 4,000 feet where greatest in Pennsylvania, and over 8,000 feet in Nova Scotia. The maximum thickness of the rocks of the Carboniferous age in Pennsylvania is about 9,000 feet, though not over 6,000 feet in any one sec-

tion; while in Nova Scotia, at the Joggins, there are, according to Logan and Dawson, 14,570 feet. The coal-fields in some regions are broken more or less into patches, either by uplifts that have brought lower rocks to the surface, or by the occurrence of overlying deposits. Those of the Interior basin are but little subdivided, while that of the great Appalachian Mountain region is in many pieces, as illustrated on the annexed map of a part of Pennsylvania. Between the various patches,

Fig. 613.



Map of part of Pennsylvania, showing the Coal areas of the State, *in black*; also the Mesozoic red sandstone formation, *obliquely lined across.*

from Pottsville to the Lackawanna coal-field, the outcropping rocks are mostly Devonian and Subcarboniferous.

II. Kinds of Rocks.

1. *Stratification.* — The Carboniferous period opened with a marked change over the continent. The Subcarboniferous limestones and shales, which had been formed upon the submerged land, became

covered with extensive gravel or pebble beds, or deposits of sand; and these, hardened into gritty rocks, make up the *millstone grit* and sandstone which underlie the Coal-measures. Similar conglomerates and sandstones were formed afterward in the course of the Coal-measures; but this rock is prominent for its extent, and for marking the commencement of the Coal era.

The rocks of the Carboniferous period are accordingly divided into (1) The *Millstone grit* section; and (2) the *Coal-measure* section.

The Millstone grit extends over parts of some of the southern counties of New York, with a thickness of twenty-five to sixty feet; and, owing to the regularity of the joints, in Cattaraugus and Alleghany counties, it stands out in huge blocks, walls, and square structures, that have suggested such names as "Rock City" and "Ruined City." It occurs through all the Coal-areas of Pennsylvania, both the eastern and western; it is from 1,000 to 1,500 feet thick, about the centre of the anthracite region, and diminishes rapidly to the westward. It stretches southwestward through Virginia and Tennessee, to Alabama. Throughout the Appalachians, it is commonly a conglomerate; but, in the Interior basin, the beds are mainly arenaceous sandstones, and in some parts are absent.

The Coal-measures include all the kinds of sedimentary rocks: sandstones, laminated or shaly sandstones and shales; conglomerates, fine and coarse; buhrstone (a cellular siliceous rock), and limestones. Interstratified with these rocks occurs the coal in layers, and often, also, beds of iron-ore. There is no fixed order of superposition. The following is an example, from Western Pennsylvania, as published by Lesley: the beds are numbered in accordance with their succession, beginning below, —

	Feet.
A. Millstone Grit	?
1. **Coal** No. A, with 4 feet of shale	6
2. Shale and mud-rock	40
3. **Coal** No. B. (Of Mammoth bed of *Central* Pennsylvania.)	3–5
4. Shale, with some sandstone and IRON-ORE	20–40
5. FOSSILIFEROUS LIMESTONE	10–20
6. Buhrstone and IRON-ORE	1–10
7. Shale	25
8. **Coal** No. C. The Kittanning Cannel	3½
9. Shale, — soft, containing two beds of **Coal**, 1 to 1½ feet thick	75–100
10. Sandstone	70
11. Lower Freeport **Coal** No. D	2–4
12. Slaty sandstone and shale	50
13. LIMESTONE	6–8
14. Upper Freeport **Coal**, No. E	6
15. Shales	50
16. MAHONING SANDSTONE	75
17. **Coal** No. F	1

		Feet.
18.	Shale; thickness considerable	?
19.	Shaly sandstone	30
20.	Red and blue calcareous marlytes	20?
21.	Coal No. G	1
22.	LIMESTONE fossiliferous	2
23.	Slates and shales	100
24.	Gray clayey sandstone	70
25.	Red marlyte	10
26.	Shale and slaty sandstone	10
27.	LIMESTONE, non-fossiliferous	3
28.	Shales	32
29.	LIMESTONE	2
30.	Red and yellow shale	12
31.	LIMESTONE	4
32.	Shale and sand	30
33.	LIMESTONE, with bands of spathic IRON-ORE	25
34.	Pittsburg Coal, No. H	8, 9

In other regions the succession is widely different. The rocks are distinguished from those of other ages, not by their colors or kinds, nor by their succession, but by the species of fossil plants and animals they contain.

The Coal beds are thin, compared with the associated rock strata, usually not exceeding *one-fiftieth* of the whole thickness.

The rock underlying a coal bed may be of either of the kinds mentioned; but usually it is a clayey layer (or bed of fine clay), which is called the *under-clay*. Being frequently suitable for making fire-brick, such beds often go by the name of *fire-clay*. This under-clay generally contains fossil plants, and especially the roots or under-water stems of Carboniferous plants, called *Stigmariæ*, and it is often called the old dirt-bed, or the bed of earth over which the plants grew that

Fig. 614.

Section of Coal-measures at the Joggins, Nova Scotia (with erect stumps in the sandstone, and rootlets in the under-clays)

commenced to form the coal-bed. It is either this, or the clayey bottom of the plant-bearing marshes or lakes. In some cases, trunks of trees rise from it, penetrating the coal layer and rock above it.

The Nova Scotia Coal region abounds in erect trunks, standing on the old "dirt-beds," as illustrated in Fig. 614, from a memoir by Dawson. Each of the seventy-six coal seams at the Joggins has its dark clayey layer, or "dirt-bed," beneath. In fifteen of them, there is only a trace of coal; but these, as well as the rest, contain the *Stigmariæ*, and often support still the old stumps.

The limestones are more extensive in the Coal-measures of the Mississippi basin than in those of Pennsylvania and Virginia, while, on the contrary, conglomerates are much less common in the West. This accords with the fact, learned from the earlier ages, that the Appalachian region is noted for its conglomerates and sandstones, and the Interior basin for limestones.

The rock capping a coal-bed may be of any kind, for the rocks are the result of whatever circumstances succeeded; but it is common to find great numbers of fossil plants, and fragments or trunks of trees, in the first stratum.

The shaly beds often contain the ancient ferns, spread out between the layers with all the perfection they would have in an herbarium, and so abundantly that, however thin the shale be split, it opens to view new impressions of plants. In the sandstone layers, broken trunks of trees sometimes lie scattered through the beds. Some of the logs in the Ohio Coal-measures, described by Dr. Hildreth, are fifty to sixty feet long and three in diameter.

2. *Coal Beds.* — The thickness of the coal beds at times hardly exceeds that of paper; and again it is from thirty to forty feet. Some of the larger beds may extend continuously over thousands of square miles; but, if so, they vary greatly in thickness; and many beds thin out laterally, or graduate into coaly-shales, in the course of a few scores of miles. Shaly layers sometimes make up a large part of the so-called coal-bed. The Mammoth bed of the Lackawanna region is, at Wilkesbarre, twenty-nine and one half feet thick; while in western Pennsylvania, according to the section by Lesley on page 311, the thickness is but three to five feet. Where thickest, it is nearly pure coal; yet there are some black shaly layers, one to twelve inches thick. The same great bed is worked at Carbondale, Beaver Meadows, Mauch Chunk, Tamaqua, Minersville, Shamokin, etc.

The Pittsburg bed, at Pittsburg, Penn., is ten feet thick; but it is made up of one foot, at bottom, of coal with pyritiferous shale; five to six feet of good coal; and, above this, shale and coal, left as the roof in working, though sometimes including one or two feet of pure coal. It borders the Monongahela for a long distance, the black horizontal band being a conspicuous object in the high shores, and in some places containing seven or eight feet of good coal. It may be traced, accord-

ing to Rogers, into West Virginia and Ohio, over an area at least two hundred and twenty-five miles by one hundred; and into Kentucky, according to Lesquereux. It varies in thickness, being twelve to sixteen feet in the Cumberland basin, six feet at Wheeling, four to eight feet in Athens County, Ohio, four feet two inches at Pomeroy, where it is the "Pomeroy" bed, six and one-half to nine and one-half feet in West Virginia, at Morgantown, and farther south, on the Guyandotte, two to three feet.

At Pictou, in Nova Scotia, one of the coal-beds has the extraordinary thickness of thirty-eight feet, and a second fifteen and one half feet.

A bed of coal, even when purest, consists of distinct layers. The layers are not usually separable, unless the coal is quite impure from the presence of clay; but they are still distinct in alternating shades of black, and may be seen in almost any hand specimen of the hardest anthracite, forming a delicate, though faint, banding of the coal.

In some of the bituminous coal of the Interior basin, a cross-fracture shows it to be made up of alternate laminæ of black, shining, compact bituminous coal, and a soft, pulverulent carbonaceous matter, looking much like common charcoal.

The Coal-measures, from the bottom (No. 1) to No. 15, in the preceding section, are sometimes designated the *Lower* Coal-measures. Of the rest, or *Upper* division, Nos. 16 to 33 are called the Barren Measures.

3. *Kinds of Mineral Coal.* — The Mineral Coals, setting aside impurities, are essentially compounds of carbon (the fundamental element of charcoal), hydrogen, and oxygen. The carbon varies from 75 to 93 per cent., or, impurities excluded, — which constitute usually 2 to 10 per cent., — from 77 to 98 per cent. The most of them yield, when highly heated, mineral oil or mineral tar, along with some inflammable gas; and it is owing to this that they burn with a bright yellow flame. The oil, like the most of the gas, consists of carbon and hydrogen. The coals, like the black carbonaceous shales mentioned on page 268, do not contain mineral oil, any more than hydrocarbon gas, as is shown on treatment with the solvents of mineral oils. The oil is a product, and not an educt. Since such oils, tars, and gas burn like bitumen, and with similar odor, coals of this kind are said to be *bituminous*, although actually containing no bitumen, and also yielding none, — bitumen being mainly an oxygenated hydrocarbon, and thus differing from mineral oil. Coals also contain traces of nitrogen; they afford generally 3 to 5 per cent., or more, of moisture, which is driven off at a temperature of 250° F.

The following are the characters of the kinds of Carboniferous mineral coals: —

1. *Anthracite*, which has high lustre and firmness, and burns with a feeble flame, yielding little moisture, only traces of hydrocarbon gas, and 84 to 95 per cent. of carbon. Specific gravity 1·3 to 1·8. *Free-burning* anthracite, or *Semi-anthracite*, affords more flame, and of a yellow color; but still the proportion of volatile matters given off is small, not exceeding 10 or 12 per cent.

2. *Bituminous Coal*, having less firmness and lustre than anthracite, and burning with an abundant yellow flame, the volatile combustible substances afforded amounting usually to 25 or 35 per cent. of the whole, and sometimes to 50 or 60 per cent. When these substances are only 15 to 20 per cent., the coal is called *semi-bituminous*. There are in fact all grades, between the true bituminous coal and the hardest anthracite. Ordinary bituminous coal breaks with straight or irregular lustrous surfaces: it sometimes divides into rectangular blocks, but this is a result of a jointed structure, and never of crystallization. Specific gravity mostly between 1·22 and 1.32.

Some bituminous coals soften in the fire, becoming semi-pasty, and then cake over; such kinds are called *caking* coals. Others, undistinguishable from the caking, both chemically and physically, are *non-caking*. The "Block Coal," of Ohio, Indiana, and the neighboring States, is of the non-caking kind.

Cannel Coal (or *Parrot Coal*) is a variety of bituminous coal having almost no lustre, a very fine texture, and a conchoidal fracture. It is remarkable for the large proportion of volatile combustible material, or mineral oil, which it yields. It received its name from its affording a flame, like candles. *Torbanite*, a variety of cannel from Torbane Hill, near Bathgate, in Scotland, yields over 60 per cent. of volatile substances.

Anthracite is the coal of Rhode Island, and of the areas in central Pennsylvania, from the Pottsville or Schuylkill coal-field to the Lackawanna field (see map, page 310); while the coal of Pittsburg, and of all the great coal-fields of the Interior basin, is *bituminous*, excepting a small area in Arkansas. Anthracite belongs especially to regions of upturned rocks, and bituminous coal to those where the beds are little disturbed. In the area between the anthracite region of central Pennsylvania and the *bituminous* of western, and farther south, the coal is *semi-bituminous*, as in Broad Top, Pennsylvania, and the Cumberland coal-field, in western Maryland, the volatile matters yielded by it being 15 to 20 per cent. The more western parts of the Anthracite coal-fields afford the free-burning anthracite, or semi-anthracite; as at Trevorton, Shamokin, and Birch Creek.

Albertite, from the Nova Scotia Subcarboniferous (p. 296), and *Grahamite*, from the Carboniferous in West Virginia (about twenty miles south of Parkersburg), are pitch-like substances in aspect, constituting veins instead of beds, and not true coals. They are supposed to have originated in distillation from some underlying carbonaceous shales, which set free the material, as Wurtz observes, in a pasty state. Though like asphaltum in color and lustre, they are not as fusible or as soluble in benzine or ether.

The following are analyses of a few of the coals of the Carboniferous period. Others, of albertite and of the more recent coal, called brown coal, and also of peat (the ash excluded), are added for comparison.

	Carbon	Hydr.	Ox.	Nitr.	Sulph.	Ash.	Analysts.
1. Anthracite, Pennsylvania . .	90·45	2·43	2·45	–	–	4·67,	Regnault.
2. Anthracite, Pennsylvania . .	92·59	2·63	1·61	0·92	–	2·25,	Percy.
3. Anthracite, South Wales . . .	92·56	3·33	2·53	–	–	1·58,	Regnault.
4. Caking Coal, Kentucky . . .	74·45	4·93	13·08	1·03	0·91	5·00,	Peters.
5. Caking Coal, Nelsonville, O. .	73·80	5·79	16·58	1·52	0·41	1·90,	Wormley.
6. Caking Coal, South Wales . .	82·56	5·36	8·22	1·65	0·75	1·46,	Noad.
7. Caking Coal, Northumberland .	78·69	6·00	10·07	2·37	1·51	1·36,	Tookey.
8. Non-caking, Kentucky . . .	77·89	5·42	12·57	1·82	3·00	2·00,	Peters.
9. Non-caking, "Block Coal," Ind.	82·70	4·77	9·39	1·62	0·45	1·07,	Cox.
10. Non-caking, Briar Hill, Ohio .	78·94	5·92	11·50	1·58	0 56	1·45,	Wormley.
11. Non-caking, S. Staffordshire .	76·40	4·62	17·43	–	0·55	1·55,	Dick.
12. Non caking, Scotland . . .	76·08	5·31	13·33	2·09	1·23	1·96,	Rowney.
13. Cannel Coal, Breckenridge . .	68·13	6·49	5·83	2·27	2·48	12·30,	Peters.
14. Cannel Coal, Wigan	80·07	5·53	8·10	2·12	1·50	2·70,	Vaux.
15. Cannel Coal, "Torbanite" . .	64·02	8·90	5·66	0·55	0·50	20·32,	Anderson.
16. Albertite, Nova Scotia . . .	86·04	8·96	1·97	2·93	*trace*	0·10,	Wetherill.
17. Brown Coal, Bovey	66·31	5·63	22·86	0·57	2.36	2.27,	Vaux.
18. Brown Coal, Wittenberg . . .	64·07	5·03	27·55	–	–	3·35,	Baer.
19. Peat, light brown (imperfect) .	50·86	5·80	42·57	0·77	–	–	Websky.
20. Peat, dark brown	59·47	6·52	31·51	2·51	–	–	Websky.
21. Peat, black	59·70	5·70	33·04	1·56	–	–	Websky.
22. Peat, black	59·71	5·27	32·07	2·59	–	–	Websky.

The Coal No. 4, from "Roberts' seam," Muhlenburg County, Kentucky, has sp. gr. $=1·26$; No. 9, from "Wolf Hill," Daviess County, Indiana, has sp. gr. $=1·275$.

No. 13, the Breckenridge cannel, of Hancock County, Kentucky, consists, when the ash is excluded, of carbon 82·36, hydrogen 7·84, oxygen 7·05, nitrogen 2·75; and the Bog-head cannel of Scotland, called also *torbanite*, contains carbon 80·39, hydrogen 11·19, oxygen 7·11, nitrogen and sulphur 1·31.

The "Mineral charcoal" differs little in composition from ordinary bituminous coal: there is less hydrogen and oxygen. Rowney obtained, for that of Glasgow and Fifeshire, Carbon 82.97, 74·71, hydrogen 3·34, 2·74, oxygen 7·59, 7·67, ash 6·08, 14·86. The nitrogen is included with the oxygen; it was 0·75 in the Glasgow charcoal. Exclusive of the ash, the composition is, Carbon 88·36, 87·78, hydrogen 3·56, 3·21, oxygen and nitrogen 7·28, 9·01.

The following are average results, from many analyses:—

	Nos.	Sp. gr.	Vol. combust.	Fixed Carbon.	Ash.	Analysts.
1. Pennsylvania anthracites .	7	1·59–1·61	3·92	89·77	6.31	Johnson.
	16	1·39–1·60	5·70	88·23	6·07	Geol. Survey.
2. Pennsylvania semi-anthracites	11	1·33-1·45	9·98	82·86	7·16	Geol. Survey.
3. Pennsylvania semi-bituminous	6	1·30–1·41	16·85	72·95	10·20	Johnson.
4. Maryland semi-bituminous .	9	1·30–1·43	15·50	74·03	10·47	Johnson & Geol. Survey.
5. Pennsylvania bituminous .	10	– –	28·35	65·18	6·47	Johnson.
6. Virginia bituminous . . .	11	1·29–1·45	29·88	59·06	11·06	Johnson.
7. Ohio bituminous	142	1·24–1·47	35·24	60·26	4·50	Wormley.
8. Indiana bituminous . . .	126	1 19–1·41	43·20	53·47	3·33	Cox.
9. Illinois bituminous	50	1·21–1·35	31·90	62·44	5·66	Blaney.
10. Iowa bituminous	59	–	–	43·02	6·82	Emery.

The ordinary *impurities* of coal, making up its ash, are silica, a little potash and soda, and sometimes alumina, with often oxyd of iron, derived usually from sulphid of iron, besides, in the less pure kinds, more or less clay or shale. The amount of ash does not ordinarily exceed 6 per cent., but it is sometimes 30 per cent.; and rarely it is less than 2 per cent. There is present in most coal traces of sulphid of iron (pyrite), sufficient

to give sulphur fumes to the gases from the burning coal, and sometimes enough to make the coal valueless in metallurgical operations. Some thin layers are occasionally full of concretionary pyrite.

Sulphur also occurs, in some coal-beds, as a constituent of a resinous substance; and Wormley has shown that part of the sulphur in the Ohio coals is in some analogous state, there being not iron enough present to take the whole into combination.

Wormley gives the following analyses (besides others) of the ash of two coals, one from the Youghiogheny, in Western Pennsylvania, and the second from Pigeon Creek, Jackson County, Ohio: Silica 49·10, 37·40, alumina 38·60, 40·77, sesquioxyd of iron 3·68, 9·73, magnesia 0·16, 1·60, lime 4·53, 6·27, potash and soda 1·10, 1·29, phosphoric acid 2·23, 0·51, sulphuric acid 0·07, 1·99, sulphur (combined) 0·14, 0·08, chlorine *trace* = 99·61, 99·64. The fact that there is too much sulphur in the Ohio coals for combination with the iron present, is shown in the following table, containing some of his results: —

Sulphur in the coals	0·57	1·18	2·00	0·91	0·86
Iron in the coals	0·075	0·742	0·425	0·122	0·052
Sulphur required by the iron	0·086	0·848	0·486	0·139	0·06

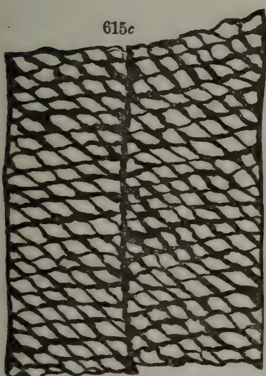
The average amount of ash, in eighty-eight coals from the southern half of Ohio, according to Wormley, is 4·718 per cent.; in sixty-six coals from the northern half, 5·120; in all, from both regions, 4·891; or, omitting ten, having more than ten per cent. of ash, the average is 4·28. In eleven Ohio cannels, the average amount of ash was 12·827.

In rare cases, an occasional bowlder or rounded stone has been found in a coal-bed, as well as in other layers of the Coal-measures. E. B. Andrews describes one of quartzyte, lying half buried in the top of the Nelsonville coal-bed, at Zaleski, Ohio, which was twelve and seventeen inches in its two diameters. F. H. Bradley reports one, also of quartzyte, about four by six inches, found in the middle of the coal-bed mined at Coal Creek, East Tennessee. These may have been dropped from the roots of floating trees, as are the masses of basaltic rocks occasionally found upon the coral atolls of the Pacific.

4. *Vegetable Remains in the Coal.* — In many places, there are vegetable remains in the coal itself, such as impressions of the trunks

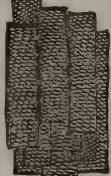
Figs. 615–616.

615c



615a

615b



616

Fig. 615 *a*, *b*, *c*, Vegetable tissues in anthracite; 616, Spores and part of a Sporangium, in bituminous coal of Ohio (× 70).

or stems of trees, or of leaves, or charcoal-like fragments, which in texture resemble charcoal from modern wood; but which have been found to be carbonized stems, leaves, or tissues of plants.

Even the solid anthracite has been found to contain vegetable tissues. On examining a piece partly burnt, Professor Bailey found that it was made up of carbonized vegetable fibres. The preceding figures, 615 *a*, *b*, *c*, are from his paper on this subject. He selected specimens which were imperfectly burnt (like Fig. 615 *a*), and examined the surface just on the borders of the black portion. Fig. 615 *b* represents a number of ducts, thus brought to light, as they appeared when moderately magnified, and Fig. 615 *c*, two of the ducts, more enlarged; the black lines being the coal that remained after the partial burning, and the light spaces *silica*. The ducts were one tenth of a millimeter (about four thousandths of an inch) broad. Dawson reports like results with bituminous coal.

The spores (fruit-cellules) and the spore-cases (sporangia) of the Lycopods (Lepidodendrids) abound in the coal, to such an extent, in some places, that it has been suggested that mineral coal was made mainly out of them. While, as Dawson has shown, this inference is not sustained by facts, such spore-cases are still very common in most coal. (The *Lycopodium* powder of the shops, used in fire works, on account of its inflammability, consists of the spores of the common species of the woods of Europe.) Fig. 616 represents, very much magnified, the surface of a piece of Ohio bituminous coal, showing a fragment of a spore-case and many of the spores. The spore-cases vary in size, from a tenth to a hundredth of an inch; and in the coal they often have an amber-yellow color. Dr. Dawson states that he has a specimen of Pennsylvania anthracite full of spore-cases, but that the Pictou coal is remarkably free from them.

5. *Iron-ore Beds.* — The iron ore of the Coal-measures is usually in the form of concretionary masses, sometimes closely aggregated into a bed from a few inches to three or four feet thick, and sometimes distributed through a shaly or calcareous layer, and often too sparsely to be of economical value. The ore is generally the carbonate of iron, called *siderite* (or often *spathic iron*). It contains as impurity ten to thirty per cent. or more of silica and other earthy matters, and hence is called *clay-ironstone*.

The concreting took place amid the sediments, and sometimes through silica; and hence a portion of the sediments is included. Such ores are of a bluish-gray or drab color, and are easily distinguished from other stones by the weight. In the Coal-measures of Pennsylvania, according to Lesley, the most valuable layer for its iron ore is the buhrstone bed, in the Lower Coal-measures, between the Coal-beds B and C in the section on page 311; but at Johnstown, on the Conemaugh, the ore used at the iron works is from a layer sixty feet above the Coal-bed E. No valuable deposits are known in the anthracite region.

Some of the clay-ironstone has the composition of *limonite*, or the hydrous oxyd of iron; but, in general, the limonite beds have been made through the alteration of the siderite (p. 58). Occasionally, the ore of the Coal-measures is *hematite*, or the red oxyd of iron.

The iron-ore beds often contain remains of plants, in the form of stems and leaves; and the concretions, which are of siderite, and of very fine texture, often include portions of ferns, with even impressions of the hairs of the surface well preserved; and also remains of Insects, Spiders, Centipedes, Amphibians, etc., all wonderfully perfect.

(*a.*) *Eastern-border region.* — In Nova Scotia, at the Joggins, over beds in some places 3,000 feet in thickness, regarded as Subcarboniferous, there are, according to Logan and Dawson, beds of sandstone, conglomerates, shale, impure calcareous layers, "dirt-beds," and thin coal-beds, of an aggregate thickness of about 13,000 feet. Dawson gives the same as the thickness in Pictou; and Mr. R. Brown makes the thickness at Cape Breton, above the Subcarboniferous, 10,000 feet. Of the 13,000 feet at the Joggins, Dawson refers 5,000 to 6,000 feet to the Millstone-grit horizon; 4,000 feet to the "Middle" Coal formation, or "Coal-measures proper," and 3,000 feet, or more, to the "Upper" Coal formation. The last, or part of it, he has since referred to the Permian. The Millstone-grit portion includes thick beds of coarse gray sandstones, containing prostrate trunks of Coniferous trees in its upper and middle parts, with red and comparatively soft beds in its lower; many layers of coaly shale occur throughout, but no coal beds. In the Coal-measures proper, there are dark-colored shales and gray sandstones, with no conglomerates or marine limestones; they comprise several coal beds, and many "dirt-beds." The uppermost series consists of sandstones, shales, and conglomerates, with a few thin beds of limestone and coal. Many of the beds of sandstone and shale are red.

Over New Brunswick, the formation is little disturbed; and, according to Dawson, the thickness near Bathurst is 400 feet. The coal beds are very thin, and of little productive value, the thickest but two feet.

At the Joggins, — of the *Cumberland* coal-region, — the main coal-bed is five feet thick, with an intercalated bed of clay, a foot or less in thickness. At Pictou, where the beds dip 20°, the average thickness of the main coal bed is 38 feet; 159 feet below this, there is the "deep seam," 15½ feet thick; and, 280 feet still lower, the "M'Gregor seam," 12 feet thick. (Dawson.) Dawson states that there are twenty-four feet of good coal in the "main seam;" twelve feet in the "deep seam." The workings of the "main seam" are mostly confined to the upper twelve feet. The bed dips under the Gulf of St. Lawrence: its workable extent has been estimated at thirty square miles. In the Cape Breton region, according to Lesley, there is, at Glace Bay, one bed of coal, ten or eleven feet thick, but of very limited range; another of six feet; and still another of eight feet, besides smaller seams. The whole workable area has been stated at 250 square miles.

The Rhode Island Carboniferous covers the most of the southern part of the State, and extends northward, through Providence, to the northern border; there it passes into Norfolk County, Massachusetts, and thence eastward, through Bristol County to Plymouth County. The exact limits, east, west, and north, have not been made out, the stratification of the rocks being much obscured by displacements or flexures and metamorphism. There are conglomerates and slates which are supposed by Hitchcock and Jackson to be a part of the formation. The quartzose conglomerate outcrops at Newport and elsewhere, and forms a bold feature in the landscape at "Purgatory," 2½ miles east of Newport, and at the "Hanging Rocks." The stones vary in size from an inch to a foot, or more. Associated with the slate, there are beds of limestone. It has been supposed that the rocks extend along the valley of Blackstone River to Worcester, near which city there are graphitic slates.

The principal points where coal outcrops are near Providence, Cranston, Bristol, Portsmouth, Valley Falls, Cumberland, and Newport (a thin bed outcropping on the coast), in Rhode Island; and in Raynham, Wrentham, Foxborough, and Mansfield in Massachusetts. The beds are much broken and very irregular in thickness, owing to

the upturning and flexures the formation has experienced; and the coal is an exceedingly hard anthracite, because of the metamorphism. Still, the slates often contain fossil plants, part of which are identical in species with those of Pennsylvania. Near Portsmouth, at Aquidneck, three beds are reported to exist, 2 to 20 feet thick, and at Case's, one of the three is 13 feet thick; at Providence, one, of 10 feet; at Valley Falls, five, 6 to 9 feet; at Cumberland, two, 15 to 23 feet; near Mansfield, several, with the maximum thickness 10 feet. The earliest opening was made at Case's, near Portsmouth, in 1808.

(*b.*) *Appalachian Region.* — The Millstone-grit, at the base of the Coal-measures, in Pennsylvania, is mostly a whitish siliceous conglomerate, with some sandstone layers and a few thin beds of carbonaceous shale. It overlies the Subcarboniferous shale or sandstone. At Tamaqua, the thickness is 1,400 feet; at Pottsville, 1,000 feet; in the Wilkesbarre region, 200 to 300 feet; at Towanda, Blossburg, etc., where it caps the mountains, it is 50 to 100 feet thick (H. D. Rogers).

In Virginia, the thickness is in places nearly 1,000 feet; the rock is mainly a sandstone, but contains heavy beds of conglomerate. The conglomerate of the Subcarboniferous, in a similar manner, becomes an arenaceous rock in Virginia. In Alabama, the rock is a quartzose grit of great thickness: it is used for millstones. In Tennessee, there are two heavy beds of conglomerate, with several heavy coal beds between them and below both, which are generally referred to the "False Coal-measures," of the Millstone-grit epoch, though the relations of the series with that of Pennsylvania have not yet been determined by actual connected explorations.

The great Anthracite region of Pennsylvania is largely Lower Carboniferous. The Upper Carboniferous is present there (at Pottsville, Shamokin, and Wilkesbarre) up to the top of the Pittsburg group (Lesley); but the rest does not extend so far eastward. The greatest development of the Lower coal is in Pennsylvania; and of the Upper, in the States farther west. The highest beds in the series appear to occur west of the Mississippi, in Kansas, where they merge into the Permian. A section of the Coal-measures in western Pennsylvania, to the top of the Pittsburg bed, is given on pages 311, 312. The following is a section of the part above this coal-bed, in Waynesburg, Greene County, as published by J. P. Lesley, in his work entitled "Manual of Coal and its Topography": —

	Feet.
1. Shale, brown, ferruginous, and sandy	30
2. Sandstone, gray and slaty	25
3. Shale, yellow and brown	20
4. LIMESTONE, — the Great Limestone south of Pittsburg (including two **Coal** beds, $2\frac{1}{2}$ feet and 1 foot)	70
5. Shale and sandstone	17
6. LIMESTONE	1
7. Shale and sandstone	40
8. **Coal**	6
9. Shale, brown and yellow	10
10. Sandstone, coarse, brown	35
11. Shale	7
12. **Coal**	$1\frac{1}{2}$
13. LIMESTONE 4 feet, shale 4, LIMESTONE 4, shale 3	15
14. Shale 10 feet, sandstone 20, shale 10	40
15. **Coal**	1
16. Sandstone (at Waynesburg), with 4 feet of shale	24

The thickness in Pennsylvania, according to Rogers, is from 2,500 to 3,000 feet. The anthracite region, as shown on the map, page 310, is divided into three ranges, a southern, a middle, and a northern. Near Pottsville, the southern or Schuylkill range includes fifteen coal-beds, which vary from three to twenty-five feet in thickness; and the whole thickness of the coal is one hundred and thirteen feet, eighty feet of it market-

able. The average amount for the southern range is one hundred feet, and for the middle and western, sixty feet each.

In western Pennsylvania, where the coal is bituminous, the workable coal is confined to the beds A to H of the section on page 311; and B, E, and H, or the Mammoth, Freeport, and Pittsburg beds, are the largest and best.

(*c.*) *Interior-Continental Basin.* — In Ohio, the Millstone-grit is in some places a coarse conglomerate; but it often rather abruptly thins out, or passes into sandstone. In Arkansas, it is represented by a conglomerate 740 feet thick (Lesquereux).

The thin limestones of the measures in Pennsylvania, Virginia, and Tennessee, thicken somewhat as we go westward, form heavy beds in Indiana, Illinois, and western Kentucky, and occupy nearly the whole of the upper part of the section in Missouri and Nebraska, where, on the contrary, the coal-beds are few and thin. Broadhead states that the 1,900 feet of measures in Missouri contain 24½ feet of coal.

The following are regarded as the equivalents of the Mammoth and Pittsburg beds: —

(1.) *Mammoth Bed* (Second workable Pennsylvania bed). — The bed at Leonards, above Kittanning, Pa. (3½ feet thick), etc.; Mahoning Valley, Cuyahoga Falls, Chippewa, etc., Ohio; the Kanawha Salines; the Breckenridge Cannel Coal and other mines in Kentucky, the first (or second) Kentucky bed; the lower coal on the Wabash, Ind.; Morris, etc., Ill.

(2.) *Pittsburg Bed* (Eighth Pennsylvania bed). — Bed at Wheeling; at Athens, Ohio; the Pomeroy bed, Ohio; at Mulford's, in Western Kentucky, the eleventh Kentucky bed.

III. Life.

1. *Plants.*

The abundance of Fossil Plants is the most striking characteristic of the Coal era; and the remains are so widely diffused, and are distributed through so great a thickness of rock and coal, that we may be sure that we have in them a good representation of the *forest* and *marsh* as well as *marine* vegetation of the Carboniferous age. In the marine, there is little peculiar to note. The land-plants, on the contrary, reveal an expansion of some departments of the Vegetable kingdom, which would not have been suspected were it not for the evidence in the rocks.

This terrestrial vegetation began, as already shown, in the Silurian, and was well displayed before the close of the Devonian. The same orders of plants were represented, but by more numerous species. These orders, as stated on page 268, included the Acrogens, or higher Cryptogams, and the Gymnosperms, or lower Phenogams.

Of Acrogens, there were (1) *Lycopods;* (2) *Ferns;* (3) *Equiseta;* and of Gymnosperms, the *Conifers.* To these, the Carboniferous period adds the first known of *Cycads*, another tribe of Gymnosperms.

Among the lower terrestrial Cryptogams, the remains of Mosses have not been found; but of Fungi or Mushrooms some evidence has been obtained. There were no Angiosperms and no Palms.

A general idea of the character of the vegetation, and also of the

scenery of the era, may be gathered from the accompanying ideal sketch, Fig. 617.

Fig. 617. Carboniferous vegetation.

Although the vegetation was very largely cryptogamous, yet it was in a great degree *forest vegetation.* Should we collect all the existing

terrestrial Cryptogams of North America, in order to make a forest of them, the forest would hardly overtop a man's head; and the Ferns would have an undergrowth of Toad-stools, Mosses, and Lichens.

Tree-ferns, one of which stands near the middle of the sketch on page 322, now grow only in the warmer zones of the globe. The largest modern Lycopods are four to five feet in height; the ancient, the features of which are shown near the sides of the sketch, were sixty to eighty feet. The Equiseta of our North American marshes are slender, herbaceous plants, with hollow stems, and, when of large size, hardly three feet high; the Calamites of the Carboniferous marshes had partly woody trunks, and some were a score of feet, or more, in height. The damp forests of Caraccas afford the largest of the modern Equiseta; and these are thirty feet in height, but, unlike the Calamites, they are quite slender.

The Conifers of the period were abundant, and were the *modern* feature in the Paleozoic forests. But these, like the Devonian, were

Fig. 618.

Extremity of a branch of Lepidodendron, with the leaves attached.

in the main related to the Araucarian Pines (see p. 134), — a group which now lives in Araucania, Chili, and Brazil, on the continent of

South America, and in Australia and Norfolk Island, in the South Pacific, and which are therefore confined at the present time to the Southern hemisphere.

1. *Lycopods.* — The *Lepidodendrids* — tall trees, with the exterior embossed with scars in alternate or quincunx order — were of many kinds. In foliage, they resembled the Pines and Spruces of the present day, as illustrated in Fig. 618, representing the extremity of a branch,

Figs. 619–621.

619 620 621

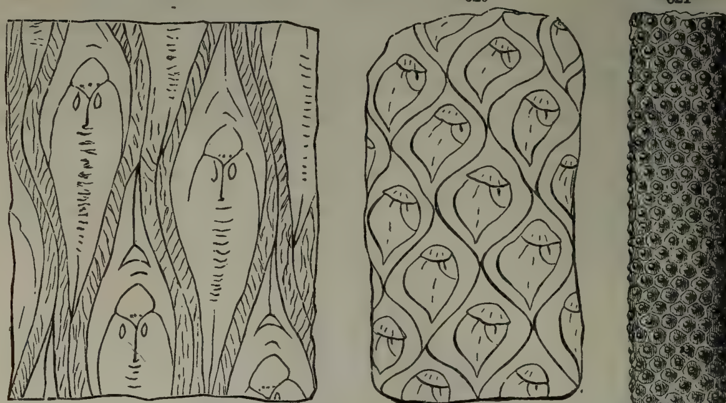


Fig. 619, Lepidodendron aculeatum, Sternb.; 620, Lepidodendron clypeatum; 621, Halonia pulchella.

restored. Leaves have been found, of the slender kind here exhibited, over a foot long; and, as the scars are the bases of the leaves, their forms and crowded position on the branch are no exaggeration. Others

Figs. 622–624.

622 623 624

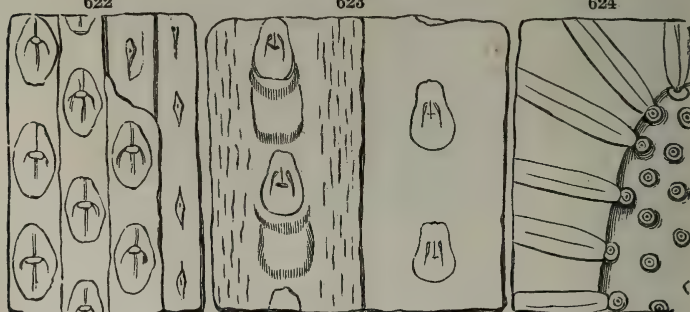


Fig. 622, Sigillaria oculata; 623, S. obovata; 624, Stigmaria ficoides.

had shorter leaves, and a more Spruce-like habit. The character and size of the scars in some of the species are shown in Figs. 619 to 621.

The *Sigillarids* differed from the *Lepidodendrids* in having the scars in vertical series, as shown in Figs. 622, 623.

In both the Sigillarids and Lepidodendrids, the appearance of the scars of the same species varied much with age; and the same scar is wholly different in form at surface from what it is below it, as shown in Figs. 622 and 623, in the part of each of which, to the right, an impression of inner surface of the stem is shown. The trunk, while woody, was not firmly so within; and it had a large pith. Stumps made hollow by decay, and now filled with sand and clay, and fossilized, are common in the Coal-measures. Of many such, there remain only casts in sand, showing an impression of the scarred exterior.

Figs. 625–629 A.

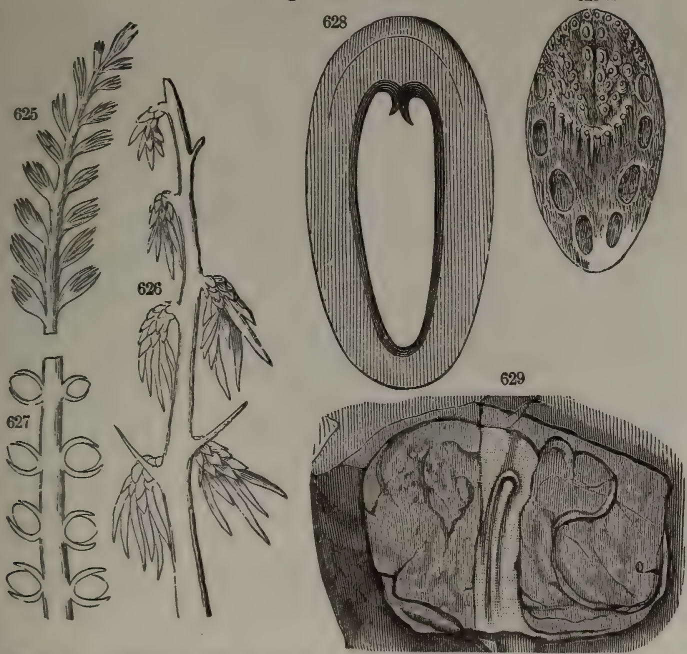


Fig. 625, Antholithes priscus; 626, A. ——? 627, A. Pitcairneæ? SCARS OF TREE-FERNS.—Fig. 628, Caulopteris punctata (× ½); 629, Megaphytum McLeayi; 629 A, Cyathea compta.

The *Stigmariæ*, described on page 269, as the under-water-stems of Sigillarids or Lepidodendrids, were often large, many of the fossil stems being four to six inches in diameter. Fig. 624 represents a portion of a stem, with its rounded depressions or scars, to each of which there is sometimes a long leaf-like appendage attached.

The accompanying figures, from Newberry, represent peculiar forms which have been supposed to be remains of flowers, and have hence

been called *Antholites.* Newberry now regards the kind represented in Fig. 625 as the fruit bearing stem of a Lycopod, of some yet undetermined kind. It is well known that many Lepidodendrids had

Figs. 630–633.

Fig. 630, Odontopteris Schlotheimii: 631, Alethopteris lonchitica; 632, Hymenophyllites Hildrethi; 632 *a*, portion of the same, enlarged; 633, Sphenopteris Gravenhorstii; 633 *a*, portion of the same, enlarged.

long cones, much resembling those of ordinary Conifers. Fig. 626 looks like the incipient stage of the form in Fig. 625. Hooker has regarded such specimens as containing undeveloped leaf-buds. Fig. 627 appears to represent the fruit of some plant, but of what there is still doubt.

2. *Ferns.* — The Ferns were mostly of the low herbaceous kinds, although Tree-ferns occurred. Some of the fronds were six to eight feet in length. Two large scars left by the fallen fronds of a Tree-fern are shown in Figs. 628, 629, and the form and structure of a

scar from a modern species (resembling that figured near the middle of the sketch, page 322), in Fig. 629 A, — all half the natural size. The trunks of Tree-ferns consist within of vertically plicated woody plates, with more or less cellular tissue between, and not of concentric rings. The twisted plates are well shown in a transverse section of a fossil trunk from the Coal-measures.

Figs. 634–641.

Figs. 634, 634 *a*, Neuropteris Loschii, parts of same leaflet: 635, Neuropteris hirsuta; 636, Pecopteris arborescens; 636 *a*, a portion of the same, enlarged; 637, Cyclopteris elegans; 638, Asterophyllites ovalis, with the nutlets in the axils of the leaves; 639, A. sublevis; 640, Sphenophyllum Schlotheimii; 641, Calamites cannæformis; 641 *a*, surface-markings of same, enlarged.

The variety of Ferns was very large. Some of the more common forms are shown in Figs. 630 to 633, and still others in Figs. 634 to 637.

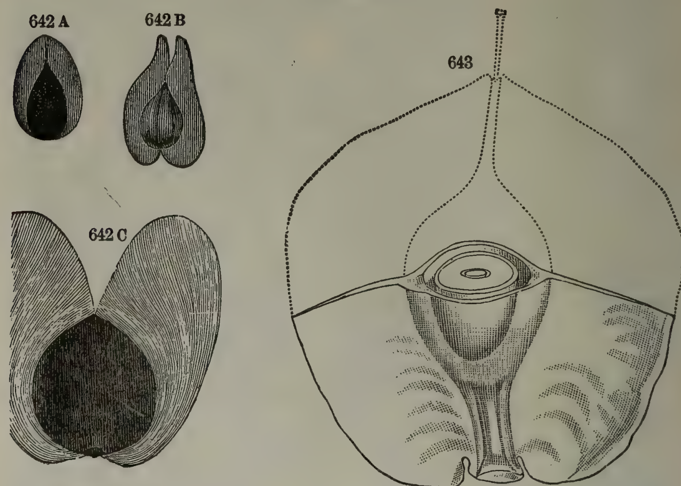
3. *Equiseta or Horsetails.* — The prominent genus of Equiseta was *Calamites*, as in the Devonian. One of the jointed stems is represented in Fig. 641.

The *Asterophyllites* (Fig. 638) were plants having the leaves, or rather branchlets, in whorls around the jointed stems, as in *Calamites;* and *Sphenophylla* are others, like Fig. 640, with the leaf-like ap-appendages broader and wedge-shaped.

The Lepidodendrids were especially characteristic of the Lower Coal-measures, as well as of the Middle and Upper Devonian. The Sigillarids and Calamites abound in the Lower, but also run through the Upper. The Asterophyllites belong especially to the Upper, though occurring below.

4. *Conifers.* — Coniferous trunks and stumps are common through the Coal-measures. *Cordaites* are strap-shaped leaves, half an inch to

Figs. 642–643.



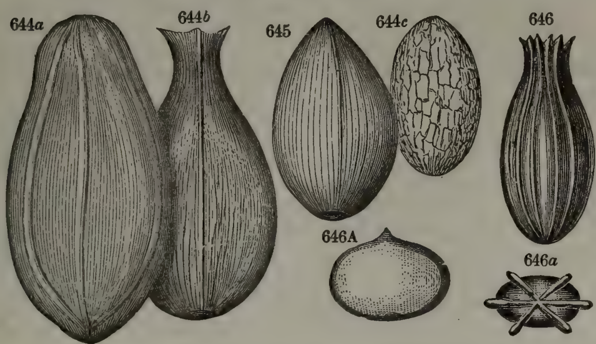
Fruits. — Fig. 642 A, Cardiocarpus elongatus; 642 B, C. bisectus; 642 C, C. samaræformis. Fig. 643, Welwitschia mirabilis, showing transverse section of fruit, with the outline of the fruit finished in dotted lines.

an inch and a half wide, sometimes short, as in the Devonian species represented on page 269, and sometimes a foot or more long. They are often crowded together in great numbers in the slates overlying the coal-beds, and are common in other positions, thus showing that they were shed in great numbers by some plants of the era. They have been referred both to the Lepidodendrids and to the Cycads, and by Schimper are embraced in Brongniart's genus *Pycnophyllum*, under the latter order. Geinitz has observed, in Saxony, and, later, Newberry, in Ohio, the winged fruits of the genus *Cardiocarpus* (Figs. 642 A, B, C) associated with the leaves of *Cordaites;* and both have regarded it as highly probable that the fruit and leaves

belong to the same plant. The nut-like character of the fruit separates *Cordaites* widely from the Lepidodendrids; and the fact that the leaves fell from the trees bearing them, instead of being persistent, and were simple instead of pinnate, removes them from ordinary Cycads, and affiliates the genus with Conifers, the other family of Gymnosperms. The South-African Conifer, *Welwitschia*, has both the broad strap-like leaves of *Cordaites*, and also, as shown in Fig. 643, the winged fruit of *Cardiocarpus;* sufficient to sustain the reference of the leaves and fruit to the Conifers, notwithstanding the anomalous character of the African plant.

Fig. 644 is a view of a large nut-like fruit of the genus *Trigono-*

Figs. 644–646 A.



FRUITS. — Fig. 644 *a*, *b*, *c*, Trigonocarpus tricuspidatus; *a*, the exterior husk or rind; *b*, the nut separate from the rind; 644 *c*, kernel; 645, nut of Trigonocarpus —— ?; 646, T. ornatus; 646 *a*, vertical view of summit, showing the six ribs of the surface; 646 A, Cardiocarpus bicuspidatus.

carpus, generally three or six-sided, whose species are common in the Coal-measures. Fig. 644 *a* is the husk; *b*, the nut; and *c*, the kernel. Fig. 645 is the nut of another species. According to Hooker, the *Trigonocarpi* most resemble the nuts of the genus *Salisburia* (of China), of the Yew family.

Characteristic Species.

1. *Lepidodendrids.* — Fig. 618, view — partly ideal — of the extremity of a branch of a *Lepidodendron.* The slender, pine-like leaves, in the *Lepidodendron Sternbergii* Brngt., as shown in magnificent specimens from the coal-mines of Radnitz, in Austria, figured by Ettingshausen, are over a foot long, and are as closely crowded about the branches as in any modern Pine. Fig. 619, part of the surface of the *Lepidodendron aculeatum* Sternb., a common species both in the United States and in Europe. Fig. 620, *L. clypeatum* Lsqx. The cones (*Lepidostrobus*) found in the same rocks with the *Lepidodendra*, are regarded as their fruit. They have some resemblance to the cones of Pines. Fig. 621 represents a portion of the stem of *Halonia pulchella* Lsqx., a plant similar to *Lepidodendron*, from the Coal-measures of Arkansas.

Fig. 625, *Antholithes priscus* Newb.; 626, *Antholithes*, species undetermined; 627, *A. Pitcairneæ* Newb.

2. *Sigillarids, Stigmariæ.* — Fig. 622, *Sigillaria oculata* Brngt., from Trevorton, Pa.; 623, *S. obovata* Lsqx., from Pennsylvania and Kentucky; 624, *Stigmaria ficoides* Brngt., portion of a stem, showing the scars and the bases of the root-like appendages.

According to Carruthers, who sustains, by his observations, the cryptogamic character of *Sigillarids* and *Stigmariæ*, the fruit of the *Sigillaria* is a cone with a single patch of small sporangia on the enlarged base of the scale. Schimper gives it the name *Sigillariostrobus*, and figures a cone.

3. *Ferns.* — Fig. 628, the scar of the Tree-fern, *Caulopteris punctata* Lsqx., from the Gate vein, Pennsylvania; Fig. 629, same of *Megaphytum McLeayi* Lsqx., from Illinois. Fig. 629 A, scar of *Cyathea compta*, a species growing in the islands of the Pacific. With the growth of the tree, as new fronds are unfolded, the old ones drop off, each of which leaves its scar. The manner in which the fronds of ferns unroll, as they expand, is shown in the sketch on page 322.

Fig. 630, portion of a frond of *Odontopteris Schlotheimii* Brngt., from Pennsylvania and Europe; the whole frond is tripinnately divided, and of very large size. This genus is mostly of the Lower Coal-measures. All the species of *Hymenophyllites*, with several of *Alethopteris*, *Neuropteris*, and *Pecopteris*, are found in the Lower Coal. Fig. 631, *Alethopteris lonchitica* Brngt., exclusively of the Lower Coal; *Sphenopteris tridactylites* Brngt. is also from the Lower Coal; Fig. 632, *Hymenophyllites Hildrethi* Lsqx., from the Kanawha Salines, and 632 *a*, the same, enlarged; Fig. 633, *Sphenopteris Gravenhorstii* Brngt., common in Ohio and farther west, at the Gate Vein, Pennsylvania, and occurring also in England and Silesia; 633 *a*, a portion of the same, enlarged.

Figs. 634, 634 *a*, *Neuropteris Loschii* Brngt., and Fig. 635, *Neuropteris hirsuta* Lsqx. from figures by Lesquereux, both very common in the Upper Coal-measures, in Ohio and Kentucky, and the former particularly abundant in the Pomeroy bed; the specimens of the latter are sparsely covered with hairs, which are well shown in specimens from Morris, Illinois. Fig. 636, *Pecopteris arborescens* Brngt., common in Pennsylvania and Ohio. *P. cyathea* Brngt. and *P. unita* Brngt. are also common in the United States, occurring in the Rhode Island coal-fields as well as elsewhere. *Alethopteris Serlii* Göpp. is another common species of the Upper Coal-measures, which is found also in Europe. Fig. 637, *Cyclopteris elegans* Lsqx., found in the Shamokin Coal-bed, Pennsylvania.

In Arctic America, on Melville Island, impressions of a *Sphenopteris* have been observed in connection with the coal.

4. *Calamitids.* — Fig. 641 represents *C. cannæformis* Schloth., one of the Lower Coal-measure species; 641 *a*, surface markings, at a joint; *C. Cistii* Brngt. and *C. nodosus* Schloth. are other American Lower-coal species, as well as foreign; *C. pachyderma* Brngt. is found only in the Millstone grit (Lesquereux).

5. *Asterophyllitids.* — Fig. 639, *Asterophyllites sublevis* Lsqx.; Fig. 638, *A. ovalis* Lsqx., with the nutlets in the axils of the leaves; Fig. 640, *Sphenophyllum Schlotheimii* Brngt., from Pennsylvania, Salem and Gate veins, and Pomeroy beds, Ohio.

6. *Gymnosperms.* — *Cordaites borassifolia* Ung. is one of the common species of the Coal-measures. Fig. 642 A, *Cardiocarpus elongatus* Newb., from Ohio; 642 B, *C. bisectus* Dn., from Nova Scotia; 642 C, *C. samaræformis* Newb., from Ohio; 644 *a, b, c*. *Trigonocarpus tricuspidatus* Newb., from Ohio, representing the rind, the nut, and the kernel; 645, nut of another Ohio species, figured by Newberry, but not described; 646, *T. ornatus* Newb., from Ohio; 646 *a*, view of extremity, showing the radiating ribs; 646 A, *Cardiocarpus bicuspidatus* Newb., from Ohio.

Fig. 643 represents the seed of the *Welwitschia*, now living in southern Africa. The *Welwitschia* is an embryonic form of Conifer; it having (1) only two leaves, the cotyledonous, these being persistent, and increasing in width and length with the age of the plant, and (2) growing to a height of only one or two feet, but spreading sometimes to a diameter of four feet, without bark; and (3) bearing a group of large and beautifully regular cones. It would seem to be, as Bentham has suggested, a type of Conifer handed down from early geological time. But no such trunks have been found in the Carboniferous or later beds. Although probably unlike *Cordaites* in its embryonic features, it shows what leaves and fruit are consistent with the type of Conifers.

Whittleseya elegans Newb., striated leaves over an inch wide and twice as long, is probably Coniferous, and related to *Cordaites*.

The *Sternbergiæ*, which are abundant in Ohio, and at Pictou, Nova Scotia, have been shown by Dawson and Williamson to be casts of the pithy or open cellular interior of either Conifers or Lepidodendrids. They are thick, cylindrical stems, much wrinkled circularly, consisting of the same arenaceous material as the rock in which they occur buried. Occasionally, they have a carbonaceous exterior, which is the woody part of the former tree. In Nova Scotia specimens, as well as those of England, a coniferous structure has sometimes been observed in the coaly exterior, and also a very open cellular structure through the sandstone interior. One of the Coal-measure species, from Pictou, is not distinguishable, in its microscopic structure, according to Dawson, from the *Pinites* (*Dadoxylon*) *Brandlingi* of Witham.

7. *Cryptogams.* — *Seaweeds* are rare in the Coal-measures. A *Spirophyton*, like *S. Cauda-galli* (p. 254), has been reported by Lesquereux as occurring in sandstone, probably of this era, or of the Subcarboniferous, in Crawford County, Arkansas. Species of the genus *Caulerpites* have been observed in Pennsylvania, Illinois, Indiana, Missouri, in both the Lower and the Upper Coal-measures. *Chondrites Colletti* Lsqx. was obtained near Lodi, Indiana, overlying a thin coal-bed at the base of the Coal-measures. Lesquereux remarks that, although the ironstone concretions have preserved the most delicate parts of Ferns and Insects, no trace of a *Fungus* or *Lichen* has been found in them.

Characteristic Species of some of the Subdivisions of the Carboniferous.

Lesquereux enumerates the following, among the species characteristic of the groups below mentioned : —

(*a.*) *Millstone Grit.* — *Lepidodendron*, six species; *Sigillaria*, two; *Calamites*, two; *Stigmaria*; and the Ferns, *Pecopteris velutina* Lsqx., *P. nervosa* Brngt., *Neuropteris flexuosa* Brngt., *N. hirsuta* Lsqx., *Annularia sphenophylloides* Ung., *Odontopteris crenulata* Brngt., *Hymenophyllites furcatus* Brngt., *Sphenopteris latifolia* Brngt., which occur also higher, to at least Coal-bed No. 1 B.

(*b.*) *Mammoth Bed* (No. 1 B). — A great number of fruits, including nearly all of the Coal-measures, of the genera *Trigonocarpus*, *Cardiocarpus*, *Rhabdocarpus*, and *Carpolithes*; numerous *Lepidodendra* (eighteen species); *Alethopteris lonchitica* and *A. marginata* Göpp., not known above, and species of *Callipteris*, with few of the finer forms of the family, of the genus *Pecopteris*; among which few there are the *Pecopteris velutina* Lsqx., *P. Sillimani* Brngt., *P. plumosa* Brngt.; *Sphenopteris* family numerously represented, — *e. g.*, *S. latifolia* Brngt., *S. obtusiloba* Brngt., *S. glandulosa* Lsqx., *S. polyphylla* L. & H., *S. Newberryi* Lsqx., *S. artemisiæfolia* Brngt., and *Hymenophyllites Hildrethi* Lsqx. and *H. spinosus* Göpp., all peculiar to it; all the American species of *Odontopteris*, except *O. crenulata* Brngt., found also in the Millstone grit. Many *Sigillariæ*, as *S. stellata* Lsqx., *S. Serlii* Brngt., *S. tesselata* Brngt., *S. Brochanti* Brngt., *S. alveolaris* Brngt., and others, not found above. The most abundant species are the omnipresent *Neuropteris hirsuta* and *N. flexuosa*. There are also species of *Annularia*, *Sphenophyllum*, *Asterophyllites*, and *Calamites*; and everywhere *Stigmaria ficoides*.

(*c.*) *Coal* No. 4. — This bed is characterized by small Ferns. There are no *Lepidodendra*, but some *Sigillariæ*; and numerous species of the *Pecopteris* family; also species of *Asterophyllites*, many of *Neuropteris*, and several of *Sphenopteris*.

(*d.*) *Coal* No. 8, *the Pittsburg Coal-bed.* — There are *Neuropteris hirsuta* Lsqx., *Cordaites borassifolia* Ung., *Neuropteris flexuosa* Brngt., *Pecopteris polymorpha* Brngt., *P. arborescens* Brngt., *P. cyathea* Brngt., *Sphenophyllum emarginatum* Brngt.; *Calamites*, three species; *Sigillaria*, one species; *Lepidodendron*, none. *Neuropteris Moorii* Lsqx. begins here, and has some resemblance to an Oölytic species.

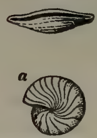
2. *Animals.*

The animal life of the Carboniferous period included, besides marine Invertebrates, terrestrial Mollusks, and a large variety of terrestrial Articulates, as Insects, Spiders, Myriapods; and, among

Vertebrates, besides Fishes and Amphibians, a higher range of life, in true Reptiles. No evidence has been obtained of the existence then of Birds or Mammals.

Among PROTOZOANS, of the Rhizopod tribe, the little *Fusulina*, related to the Nummulites of a later period, was a characteristic kind.

Fig. 646 B.



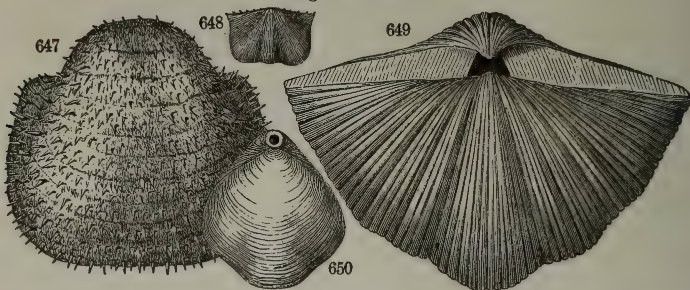
Fusulina cylindrica.

The shell, as shown in the annexed figure (Fig. 646), had nearly the shape and size of a kernel of wheat. Fig. 646 *a* shows the form as seen in a transverse direction. Internally, it contains a large number of minute cells, like other foraminifers. In Europe, it is found both in the Subcarboniferous and Carboniferous.

The RADIATES comprised Corals and Crinoids, but of less numbers than in the Subcarboniferous.

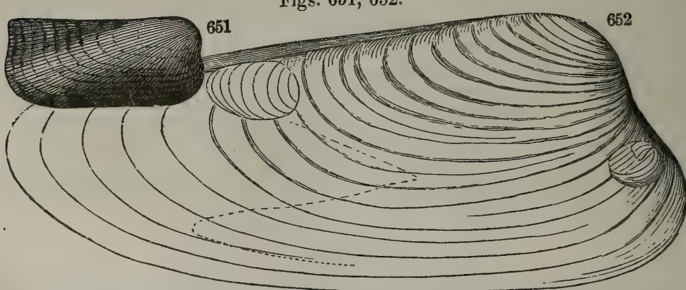
Among MOLLUSKS, Brachiopods still far outnumbered all other kinds; and with them there were some species of *Orthoceras*, *Nautilus*, and *Goniatites*, and other kinds of Paleozoic type. But with these there were land-snails, allied to the modern *Pupa*. Some of the Bra-

Figs. 647–650.



BRACHIOPODS. — Fig. 647, Productus Nebrascensis; 648, Chonetes mesoloba; 649, Spirifer cameratus; 650, Athyris subtilita.

Figs. 651, 652.



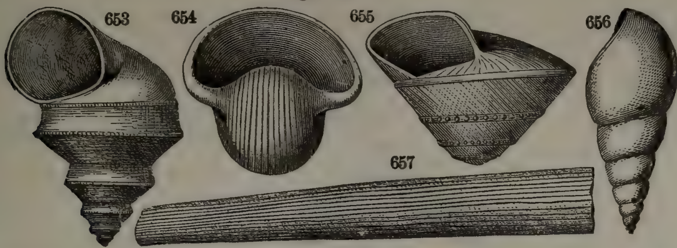
LAMELLIBRANCHS. — Fig. 651, Macrodon carbonarius; 652, Allorisma subcuneata.

chiopods are represented in Figs. 647 to 650; among them, species of the genera *Productus* (Fig. 647) and *Spirifer* (Fig. 649) were common.

Lamellibranchs were of many kinds. Two are shown in Figs. 651, 652.

The following are figures of some of the Gasteropods, one excepted,

Figs. 653–657.



GASTEROPODS.—Fig. 653, Pleurotomaria tabulata; 654, Bellerophon carbonarius; 655, Pleurotomaria sphærulata; 656, Macrocheilus (?) fusiformis; 657, Dentalium obsoletum.

Fig. 654 representing a floating shell of the old Lower Silurian genus *Bellerophon*, of the tribe of Heteropods.

Figs. 658–660.

Fig. 658, Pupa vetusta (×⅜); 659, P. Vermilionensis; 660, Dawsonella Meeki.

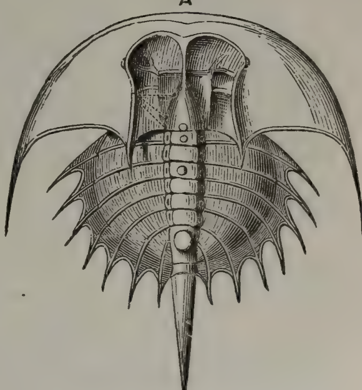
One of the small land-snails, or *Pulmonates*, is represented, a little enlarged, in Fig. 658,—a species found in the Nova Scotia Coal-measures; and Figs. 659, 660, show the forms of two others, from the Carboniferous of Illinois.

Fig. 661.

Spirorbis carbonarius.

Among ARTICULATES, the continental, rather than oceanic, character of the era is well shown. The class of Worms included a very small species, having a spiral shell (Fig. 661), and therefore called *Spirorbis*, which lived attached to the leaves and stems of the submerged plants; and, therefore, since the plants are not marine, in the fresh-water or brackish-water basins of the continent. The shell is closely like that of modern species of the genus *Spirorbis*.

Fig. 662.

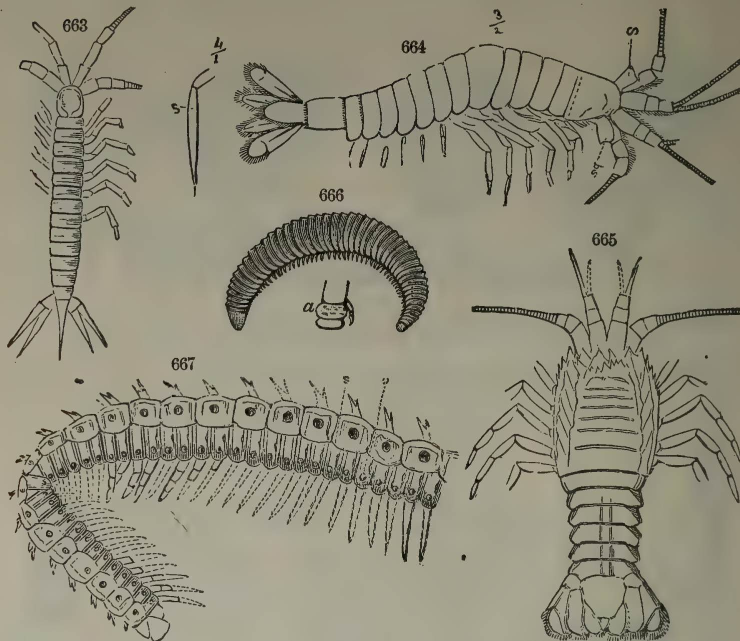


Euproöps Danæ.

The CRUSTACEANS of the era included a few Trilobites. But there were also other kinds of modern aspect. Fig. 662 represents one, closely related to the modern *Limulus*, or Horse-shoe Crab, a species of which (often a

foot long, apart from its tail spine) is common on the Atlantic coast

Figs. 663–667.



CRUSTACEANS. — Fig. 663, Acanthotelson Stimpsoni; 664, Palæocaris typus (×3); 665, Anthrapalæmon gracilis. MYRIAPODS: 666, Xylobius sigillariæ; 667, Euphoberia armigera.

Figs. 668, 668 A.

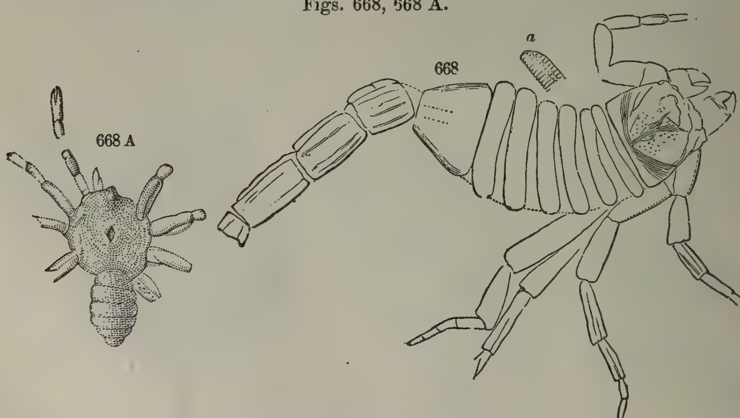


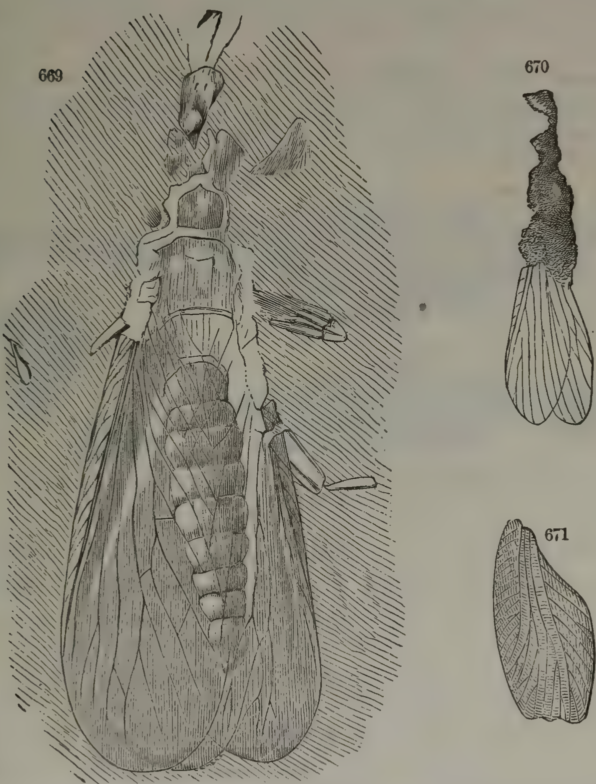
Fig 668, Eoscorpius carbonarius; 668 A, Arthrolycosa antiqua.

of North America, south of Cape Cod. The specimen here figured is

from Illinois. Other Illinois species, of more advanced type, were allied to the Shrimps, or Macrural Decapods; Figs. 664, 665 represent two of this kind. Fig. 663 is a species of Tetradecapod.

The MYRIAPODS, or Centipedes, were of the same tribe with the modern *Iulus*, or the cylindrical Myriapods, having two pairs of feet to each segment of the body. Fig. 666 represents a species from Nova Scotia, and Fig. 667, one of very large size, from Illinois.

Figs. 669–671.



NEUROPTEROUS INSECTS. — Fig. 669, Miamia Bronsoni (× 2); 670, Miamia Danæ. ORTHOPTERS. — 671, Blattina venusta.

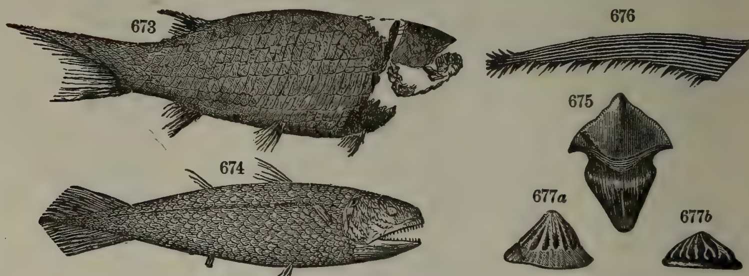
SPIDERS were represented by Scorpions, and also by true Spiders. One of the Scorpions, from Morris, Illinois, is shown in Fig. 668, and a Spider from the same locality, in Fig. 668 A.

The INSECTS, as gathered from American rocks, comprised species related to the May-fly and others, among *Neuropters;* Cockroaches, among *Orthopters.* Fig. 669 represents one of the Neuropters related

to the May-flies, twice the natural size, from Morris, Illinois; and Fig. 670, two wings of another related species. Figure 671 represents one of the posterior wings of a Cockroach, from Arkansas. Morris, Illinois, and Pennsylvania, also, have afforded specimens of the Cockroach family. Other insects have been found in Nova Scotia. One, called *Haplophlebium* by Scudder, resembles much that of Fig. 599, both in the nervures of the wing, and in size; the expanse of wing, observes Dawson, was seven inches, — indicating a species of May-fly much larger than any now living. May-flies are the kind of insect most likely to be preserved in rock deposits, because they frequent wet places.

Passing to Vertebrates, the class of FISHES had only Selachians and Ganoids, as in the Devonian; and the Ganoids had still the ancient feature of vertebrated tails. Two of these Ganoids, one with the

Figs. 673–677.



GANOIDS. — Fig. 673, Eurylepis tuberculatus; 674, Cœlacanthus elegans. SELACHIANS. — Fig. 675, Petalodus destructor; Fig. 676, Fin-spine; Fig. 677 *a*, *b*, Dermal tubercles of Petrodus occidentalis.

vertebral column extending along the middle of the tail, are illustrated in Figs. 673, 674; they are from a black shale of the Coal-measures, at Linton, Ohio, where fossil species have been found in large numbers. Many teeth and fin-spines of sharks occur in the rocks. A tooth of one of them, *Petalodus destructor*, of the tribe of *Petalodonts* (so named from the broad *leaf*-like form), is shown, one third the natural size, in Fig. 675: it is from Illinois. A portion of the fin-spine of another is represented in Fig. 676. At localities of this spine, there are frequently bony pieces, Figs. 677 *a*, *b*, which are regarded as the bony tubercles with which the surface of the body was armed. Both spine and tubercles have been referred to the same species, *Petrodus occidentalis*.

Besides Fishes there were both AMPHIBIANS and REPTILES; but the former were much the more numerous.

[1] The following are the general characteristics of Amphibians and Reptiles, and of their sub-divisions: —

In both groups the animals are air-breathing in the adult stage, like Birds and

The Amphibians were not of the naked-skinned kind of modern time, but had scales, like the Ganoid Fishes, and also like most true

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Mammals. Unlike Fishes, they have almost always a sternum; a shoulder-girdle, represented by a scapula and its appendages; two lungs, instead of an air-bladder, each with a special canal communicating with the pharynx; and the lower jaw articulated with the skull by the intervention of a special bone, the *os quadratum*. They are of low vital activity, with the temperature variable and in general directly related to that of the surrounding medium. The vertebræ differ from those of Mammals, in being convex and concave at the opposite ends, and in a few cases concave at both extremities, approximating, in this last case, to those of Fishes. The teeth, when set in sockets, never have more than one prong of insertion, while those of Mammals may have two or more.

The more obvious distinctions of Amphibians and Reptiles are :—

I. Amphibians. — Breathe when young (or in the tadpole state) by means of gills, and, with a few exceptions, undergo a metamorphosis in which they become gill-less. Heart with three cavities.

II. Reptiles. — Have no gills at any period of life, and undergo no metamorphosis. Heart with three or four cavities.

I. Amphibians (Batrachians of most authors).

In the Amphibians, the skeleton is distinguished by having (1) two occipital condyles, for the articulation of the head with the body, one placed either side of the foramen; (2) the ribs very short, or rudimentary, or wanting; (3) the skull flat and usually broad, and of a loose and open structure. The body in living species is covered with a soft skin, with sometimes minute scales, as in the Cœcilians. In an extinct group, there are distinct scales, still the species are more related to Fishes than to true Reptiles.

There are three tribes among living species, and a fourth of extinct species, if not also a fifth.

1. Cœcilians, or Snake-like Amphibians. — Body having the form of a snake; no feet.

2. Salamandroids, or *Batrachia Urodela*. — Body usually lizard-like, or resembling in form a tadpole; having short legs, as in the Salamanders; sometimes, as in *Siren*, only the two fore-feet developed; ribs short. They graduate downward into species that keep their gills through life, which, while perfect animals, are representatives of the embryonic or young state of the higher Amphibians. In others, of intermediate grade, the gill-opening is retained, but not the gills. But, in the large majority, the gills and gill-openings both disappear. Some species, like the *Siredon* or *Axolotl*, of Mexico, *Siren* and *Necturus* of the United States, and *Proteus* of the Adelsberg Cave, Carniola, retain their gills through life.

The *Menopoma* of the Alleghany region, like some others, *retains the gill-openings, but not the gills;* the animals are large, broad and flat, sometimes over two feet long. The *Amphiuma* of the Southern States also retains the gill-openings. The *Megalobatrachus* (or *Sieboldia*), of Japan, is closely related, although the gill-openings become closed up: it is the largest of the existing tailed Amphibians, having a length exceeding three feet. The fossil *Andrias Scheuchzeri* Tschudi, of the Tertiary, is related to it.

The ordinary *Salamandrids* are without gills or gill-openings, in the adult state.

In most of the North American Salamandrids, there are teeth on the vomer, and no parotid gland; while the species of Europe want these vomerine teeth, and have parotid glands.

3. Batrachoids (so named from the Greek Βάτραχος, *a frog*), or *Batrachia Anoura*. Body having four long legs (the hinder the longer) and no tail, as in the Toads and Frogs. The teeth are small, and mostly on the roof of the mouth on the vomer, with none in the lower jaw; the vertebræ are typically ten, but sometimes coalesce so as to appear fewer, the apparent number seldom exceeding eight; the ribs are wanting.

4. Labyrinthodonts. — The species of this group of extinct Amphibians resemble

Reptiles. These teeth, moreover, have the *labyrinthine* internal texture of the teeth of Ganoids (Fig. 521) ; and hence they are called Labyrin-

the Batrachoids, in having (1) double occipital condyles; (2) teeth on the vomer; (3) short, if any, ribs; (4) usually large palatine openings: and they approach Saurians in having (1) the teeth stout and conical, and set in sockets; (2) the body covered with plates or scales; (3) the size sometimes very great. The teeth have the labyrinthine arrangement of the dentine and cement that characterizes the Sauroid fishes among Ganoids (see Fig. 521), and which is still continued in that group among the living Gars; and hence the name *Labyrinthodonts.*

The GANOCEPHALA are supposed to be Labyrinthodonts, while approaching Ganoid fishes in the sculptured bony plates which covered the head, and in some other characters. — Ex., *Archegosaurus* and *Apateon*

II. REPTILES.

The skeleton in the true Reptiles has (1) but one occipital condyle below the foramen; (2) a series of ribs; (3) a covering of scales or plates, with rare exceptions.

The existing species, and part of the extinct, belong to three tribes: —

1. SNAKES, or OPHIDIANS. — (1) Body without legs, with rare exceptions; (2) no sternum; (3) eyes without lids; (4) no external ear.

2. SAURIANS. — Body (1) without a carapax, and with a tail; and having (2) four feet (rarely two, or none); (3) a sacrum corresponding to two united vertebræ, sometimes more; (4) eyes with lids, or seldom without; (5) usually an external ear-opening.

3. TURTLES, or CHELONIANS. — Body having (1) a carapax, or shell, made of several pieces firmly united ; (2) a very large sternum, forming the under surface of the body; (3) a horny beak, instead of teeth; (4) an external ear opening; (5) neck and limbs very flexible.

Saurians. — The Saurians vary in length from a few inches to fifty or more feet. In some, the teeth are set in sockets, as in the Thecodont Saurians (so named from θήκη, *a case*, and ὀδοῦς, *tooth*) and Crocodilians. In others (Pleurodonts), the teeth are implanted in a groove, the outer border of which projects more than the inner; in others (Acrodonts), they are soldered firmly to the salient part of the jaw-bone.

The prominent tribes are the following, beginning with the highest in rank: —

1. DINOSAURS (δεινός, *terrible*, and σαῦρος, *lizard*). — Reptiles of great size, all now extinct, having some mammalian and many bird-like characteristics: (1) the long bones have a medullary cavity; (2) the pelvic arch and the hind-feet are nearly as in Birds; (3) the sacrum consists of at least four vertebræ, a mammalian feature; (4) the cervical vertebræ are convexo-concave, as in Mammals; (5) the lower jaw in some species has lateral motion, for trituration. They include the *Megalosaur* (p 445), *Hylæosaur*, *Iguanodon*, *Hadrosaur*, etc.

2. CROCODILIANS, or *Cuirassed Saurians.* — Body having (1) a cuirass, made of bony plates; (2) large, conical teeth, in sockets, in a single row; (3) one jugale; two premaxillary bones; (4) sacrum formed in general of two vertebræ; (5) heart with four cavities; external nostrils at the extremity of the snout. The modern species have *concavo-convex* vertebræ, — that is, the anterior face is concave and the posterior convex; in others, of the Teleosaur group, including the extinct *Teleosaurs*, *Hyposaurs*, etc., they are *biconcave.*

8. LACERTIANS, or *Scaly Saurians.* — Body having (1) corneous scales; (2) the teeth rarely in sockets; (3) no jugale; one ventricle; one premaxillary bone; (4) sacrum consisting of two vertebræ, at the most. The *Lizards*, *Iguanas*, and *Monitors* are the types of the tribe.

A few extinct species characterized by small scales are *Thecodonts*, like the Crocodiles, so that they stand apart from the Lacertians, and are intermediate between them and Crocodilians. Such are the *Thecodontosaur*, *Paleosaur* and *Proterosaur* (Fig. 697, p. 373), — among the earliest of true Reptiles, and the precursors of the Crocodiles and Dinosaurs.

thodont Amphibians, or *Labyrinthodonts*. Morris, Illinois, has afforded several specimens; and one of them is represented, twice the natural size, in Fig. 678. It had the elongated tail of a Salamander. The orbits are very large, and the teeth numerous. The scales over the body were not overlapping, and appear to have been most crowded over the posterior part of the body. Other related species have been detected among the remains at Linton, Ohio; one is represented in Fig. 679, and some of the vertebræ and ribs of another species, in Fig. 680. The Coal-measures of Nova Scotia have afforded several species of related kinds. One of them, *Baphetes planiceps* Owen, had a skull seven inches broad.

The locality at Morris, Illinois, from which so many of the species above described — both Articulates and Vertebrates — were obtained, abounds in iron-stone concretions of a flattened lenticular shape; and the specimens are contained within the concretions, each having served as a nucleus, about which the concreting action went forward. The figures of these Illinois species, with the exception of Figs. 668 A and 669, are from Worthen's Geological Report of Illinois.

In Nova Scotia, remains of several of the Amphibians have been found at the Joggins, in the interior of *Sigillaria* stumps, which had become partly hollowed out by decay and afterward filled by sand and mud, in the marsh or forest where they stood, before their final burial by the deposits that were increasing around them. Figure 614, on page 312, represents a section of the part of the Coal-measures in which the stump was found that gave up the first three species of Amphibians. The discovery was made by Dawson and Lyell in 1851. Along with mineral charcoal derived from the wood, and bones of the Amphibians, there were taken from this stump more than fifty shells of the land-snail *Pupa vetusta* (Fig. 658), and a Myriapod

4. The *Mososaurs* (p. 465), on the contrary, although of large size (forty or more feet long), had the teeth in sockets, four paddles, and the body covered with bony scutes.

Besides these tribes, there are two extinct groups: —

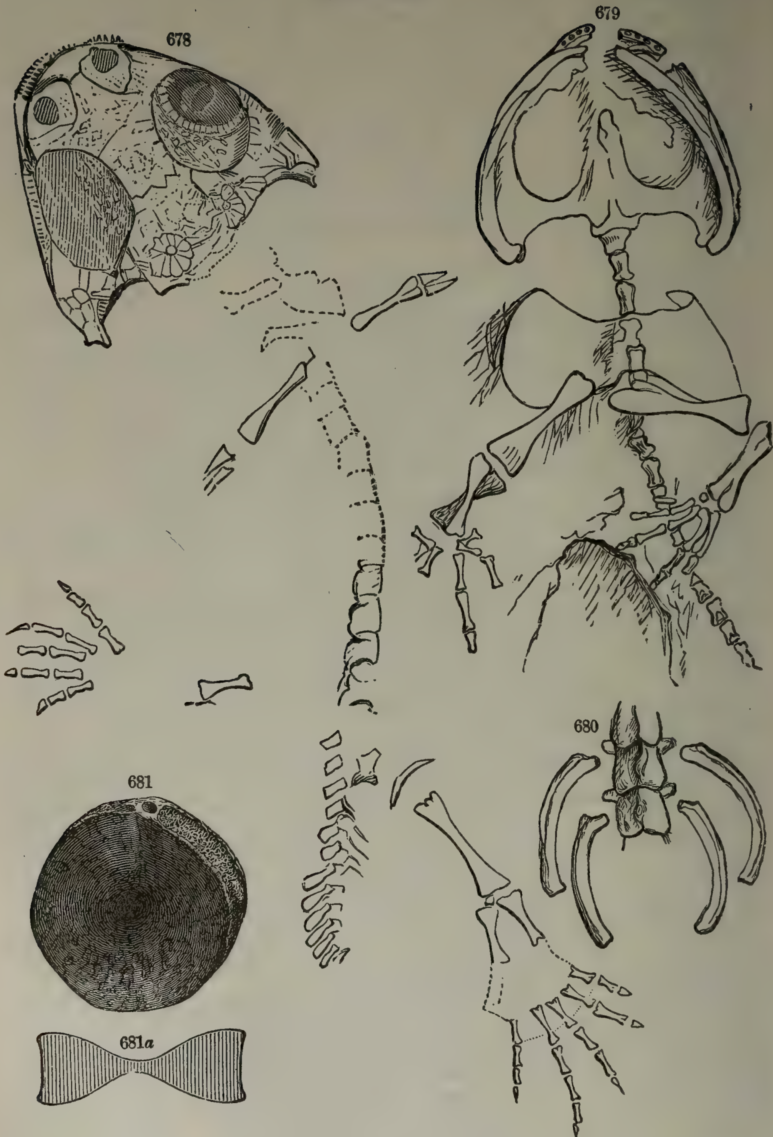
5. Enaliosaurs (from ἐνάλιος, *marine*, etc.), or *Swimming Saurians*. — (1) Furnished with paddles for swimming; (2) having the vertebræ biconcave, — another fish-like characteristic; (3) teeth large, and set in a groove. *Ichthyosaur* and *Plesiosaur* were the most common genera. (See pp. 442, 443.)

5. Pterosaurs (from πτερόν, *a wing*, etc.), or *Flying Saurians*. — The most common genus was *Pterodactylus*, p. 446. By the excessive elongation of the little finger of the fore-feet, support was afforded to a membrane which extended to the tail, and made a wing for flying. The remaining fingers were short, and furnished with claws. The long, slender jaws were set with a large number of teeth in sockets. The bones were hollow and light, as in Birds. They had the habits of Bats, and wings of a similar character. But, in Bats, all the fingers of the hand but the thumb are elongated for the purpose of the wing; and the thumb alone is used for clinging.

Chelonians. — The Turtles, or Chelonians, are of two tribes: —

1. The *Sea-Turtles*, — furnished with paddles, instead of feet.
2. The *Land-Turtles*, — furnished with feet.

Figs. 678-681.



AMPHIBIANS. — Fig. 678, Amphibamus grandiceps (×2); 679, Raniceps Lyellii; 680, vertebræ and ribs of another species. ENALIOSAUR. — Figs. 681, 681 a Eosaurus Acadianus, vertebra (×½).

(Fig. 666), besides fragments of many other specimens of the *Pupa*, and a few individuals of the small *Spirorbis*, represented in Fig. 661, on page 333. Dawson observes that the shells were probably the food of the Reptiles, adding that he has found, in the stomach of a recent *Menobranchus* (*M. lateralis* Harlan), as many as eleven unbroken shells of the fresh-water snail *Physa heterostropha*.

Such a congregation of animals in a single stump proves, as Dawson states, that the species of the tribes represented were not rare in the marshes and forests of Carboniferous Acadia.

FOOTPRINTS of Labyrinthodonts have been found in the Coal-measures of Pennsylvania, Indiana, Illinois, Kansas, and Nova Scotia; and others, apparently of true Reptiles, have been reported from Kansas.

TRUE REPTILES were represented, according to specimens of vertebræ from Nova Scotia, by the tribe of *Enaliosaurs*, or *Sea-saurians* as the word means; swimming species that had paddles instead of feet. (Jurassic kinds are represented in the figures on pages 442, 443.) Fig. 681 *a* shows the biconcave form of the vertebræ, a fish-like feature, characterizing this tribe of Saurians.

Characteristic Species.

1. **Protozoans.** — *Rhizopods.* — Fig. 646 B, *Fusulina cylindrica* Fischer; *F. gracilis* M., and *F. robusta* M.; considered varieties of one species by Meek. The foraminifers occur in vast numbers, almost making up the limestones in some places, and have been observed in Ohio, Indiana, Illinois, Missouri, Nebraska, and Kansas. In the United States, the genus *Fusulina* is confined to the Coal-measures; but in Russia it occurs also in the upper part of the Subcarboniferous rocks.

2. **Radiates.** — (*a.*) *Polyps.* — The Corals *Lophophyllum proliferum* McChesney, from Illinois, *Syringopora mult-attenuata* McChesney, *Campophyllum torquium* Ow. (*b.*) *Acalephs.* — *Chætetes milleporaceus.* (*c.*) *Echinoderms.* — *Crinoids*, of the genera *Poteriocrinus*, *Actinocrinus*, *Cyathocrinus*, *Zeacrinus*, *Erisocrinus*, *Scaphiocrinus*, *Eupachycrinus*, *Agassizocrinus*, etc.; *Echinoids*, of the Paleozoic genus *Archæocidaris*.

3. **Mollusks.** — (*a.*) *Brachiopods.* — Fig. 649, *Spirifer cameratus* Mort. (*S. Meusebachanus* R.), from the Lower and Upper Coal-measures, and occurring in Ohio, Kentucky, Indiana, Illinois, Missouri, Iowa, Kansas, Texas, New Mexico, and Utah. This species is closely allied to *S. striatus* Sow. (Figs. 221, 222, p. 171), and is regarded by some as only a variety of it; but it belongs exclusively, in this country at least, to the Coal-measures, and not to the Subcarboniferous, in which the *S. striatus* is found well marked. Fig. 647, *Productus Nebrascensis* Ow., from Illinois, Kansas, and New Mexico; Fig. 648, *Chonetes mesoloba* N. & P., a common species; Fig. 650, *Athyris* (*Spirigera*) *subtilita* Newb., very common in the Coal-measures, and not known in the American Subcarboniferous, although reported from the latter in England; there are, however, Subcarboniferous forms distinguishable with difficulty from it. *Spiriferina Kentuckensis* is an Upper Coal-measure species, from Illinois, Kentucky, Missouri, and near Pecos village, New Mexico; *Spirifer lineatus* Phill., *Meekella striato-costata* White and St. John, from Illinois, Missouri, and Iowa; *Syntrielasma hemiplicata* M. & W., Illinois and Utah; *Orthis carbonaria* Swallow; *Terebratula bovidens* Mort.; *Hemipronites crassus* M. & H.; *Cryptacanthia* (*Waldheimia*) *compacta* White & St. John.

The following first appeared in the Subcarboniferous, and are continued into the Carboniferous: *Productus punctatus* (Fig. 596, p. 300), *P. cora*, *P. muricatus*, *P. semireticulatus* (Fig. 239, p. 173), *Spirifer lineatus*.

(*b.*) *Lamellibranchs.* — Fig. 651, *Macrodon carbonarius* M., Upper Coal-measures of Kentucky; Fig. 652, *Allorisma subcuneata* M. & H., Kansas; *Aviculopecten rectilateraria* Cox, Upper and Lower Coal-measures, *Avicula* (*Gervillia*) *longa* M., *Nuculana bellistriata* M., *Cardiomorpha Missouriensis* Shum., *Solenomya radiata*, *Myalina perattenuata* M. & W., *M. recurvirostris* M. & W., *Schizodus amplus* M. & W., all from Illinois; *Astartella*, etc. *Entolium aviculatum* M., Kansas; *Pinna peracuta* Shum., Missouri, Kansas; *Lima retifera* Shum., Kansas; *Mytilus* [*Modiola* (?)] *Shawneensis* Shum., Kansas; species of *Monopteria*, *Pseudomonotis*, *Placunopsis*, etc.; *Modiola Wyomingensis* Lea, Wyoming, Pa.; *Naiadites* (*Anthracoptera*) *carbonaria* Dn., Nova Scotia; *N. elongata* Dn., Nova Scotia; *N. levis* Dn., Nova Scotia.

(*c.*) *Gasteropods.* — Fig. 654, *Bellerophon carbonarius* Cox (often referred to *B. Urii* Fleming), Upper Coal, Kentucky; Fig. 653, *Pleurotomaria tabulata* Con.; Fig. 655, *P. sphærulata* Con.; *P. carbonaria* N. & P., *P. Grayvillensis* N. & P.; Fig. 656, *Macrocheilus* (?) *fusiformis* H., *M. Newberryi* Stevens, *M. ventricosus* H., Illinois; *Murchisonia minima* Swallow, Missouri; Fig. 657, *Dentalium obsoletum* H., *D. Meekianum* Gein., from Nebraska and Illinois; *Chiton carbonarius* Stevens, *Euomphalus subrugosus* M. & W., *Loxonema semicostatum* M., *Aclis robusta* Stevens, *Streptacis Whitfieldi* M., all from Illinois; *Naticopsis* sp. Also the *Land-snail* (Helix family), *Pupa vetusta* Dn. (Fig. 658), half an inch long, from the Coal-measures of the Joggins, Nova Scotia; Fig. 659, *Pupa Vermilionensis* Bradley, from Vermilion County, Illinois, in a concretionary limestone; Fig. 660, *Dawsonella Meeki* Bradley, from same locality.

(*d.*) *Cephalopods.* — *Nautilus Missouriensis* Shum., Lower Coal-measures; *N. planivolvus* Shum., Upper Coal-measures; *Goniatites politus* Shum., near Middle Coal-measures; *G. parvus* Shum., Upper Coal-measures; *Orthoceras aculeatum* Swallow, Upper Coal-measures; *O. moniliforme* Swallow, Upper Coal-measures, — all from Missouri: *O. Rushense* McChesney, Indiana and Illinois; *Nautilus latus* M. & W., *N. Winslowi* M. & W., *N. Lasallensis* M. & W., *Goniatites compactus* M. & W., all from Illinois.

4. Articulates. — (*a.*) *Worms.* — Fig. 661, *Spirorbis carbonarius* Dn. (*Microchonchus carbonarius* Murch., *Gyromyces ammonis* Göpp), attached to leaves and stems of plants, in the measures of all the Coal-fields; *Palæocampa anthrax* M. & W., Morris, Illinois.

(*b.*) *Crustaceans.* — *Phyllopods: Dithyrocaris carbonarius* M. & W., *Ceratiocaris sinuatus* M. & W., both from Illinois. *Trilobites: Phillipsia Missouriensis*, *P. major*, *P. Cliftonensis*, — all described by Shumard, — from the Upper Coal-measures of Missouri; *P. scitula* M. & W., common in Illinois and Indiana. *Limulids:* Fig. 662, *Euproöps Danæ* M. & W., Morris, Illinois. *Eurypterids: Diplostylus Dawsoni* S., Nova Scotia; *Eurypterus Mazonensis* M. & W., from Morris, Illinois. *Ostracoids: Beyrichia Americana* Shum., from Missouri; *Leaia tricarinata* M. & W., from Upper Coal-measures, Illinois. *Tetradecapods:* Fig. 663, *Acanthotelson Stimpsoni* M. & W., Morris, Illinois; *A. Eveni* M. & W., Morris, Illinois. *Decapods:* Fig. 664, *Palæocaris typus* M. & W., Morris, Illinois; Fig. 665, *Anthrapalæmon gracilis* M. & W., Morris, Illinois.

(*c.*) *Myriapods.* — Fig. 666, *Xylobius Sigillariæ* Dn., from the Coal-measures of Nova Scotia, and related to the modern *Iulus; a*, organ (labrum?) pertaining to the mouth, with its palpus, enlarged: the species must have burrowed into the interior of the *Sigillaria* trunk in which it was found (Dawson); *X. similis* Scud., ibid.; *X. fractus* Scud., ibid.; *X. Dawsoni* Scud., ibid.; *Archiulus xylobioides* Scud., ibid.; Fig. 667, *Euphoberia armigera* M. & W., Morris, Illinois; *E. major* M. & W., Morris, Illinois; *Anthracerpes typus* M. & W., Morris, Illinois.

(*d.*) *Spiders.* — Fig. 668, *Eoscorpius carbonarius* M. & W., Morris, Illinois; *a.* Comb-like organ; *Mazonia Woodiana* M. & W., Morris, Illinois; *Architarbus rotundatus* Scud., allied to the *Phalangidæ*, Morris, Illinois; Fig. 668 A, *Arthrolycosa antiqua* Harger, a spider, from Morris, Illinois, allied to the *Protolycosa* of Rœmer in having a jointed abdomen and in other points; the generic name, signifying a *jointed Lycosa* or *Tarantula*, alludes to this Paleozoic feature.

(*e.*) *Insects.* — 1. *Orthopters*, related to the Cockroach (*Blatta*). Fig. 671, *Blattina venusta* Lsqx., from the Coal-measures, at Frog Bayou, Arkansas; a similar wing,

possibly the same species, has been found by Moore, near Pittsburgh, Pennsylvania. *Archimylacris Acadicus* Scud., East River, Pictou, Nova Scotia; *Mylacris anthracophila* Scud., Morris, Illinois.

2. *Neuropters.* — Fig. 669, *Miamia Bronsoni* D., twice the natural size, Morris, Illinois; Fig. 670, *M. Danæ* Scud., Morris, Illinois; *Hemeristia occidentalis* D., ibid.; *Haplophlebium Barnesii* Scud., Little Glace Bay, Cape Breton, Nova Scotia; *Chrestotes lapidea* Scud., Morris, Illinois; *Megathentomum pustulatum* Scud., a delicate wing, two inches in breadth, from Morris, Illinois; *Euphemerites simplex* Scud., *E. gigas* Scud., and *E. affinis* Scud., from Morris, Illinois.

5. Vertebrates. — (*a.*) *Fishes.* — Fig. 673, *Eurylepis tuberculatus* Newb.; and Fig. 674, *Cœlacanthus elegans* Newb., — both Ganoids from the Coal-measures at Linton, Ohio: the latter is remarkable for not having the tail heterocercal, although strictly vertebrated. Eight other species of *Eurylepis*, two of *Cœlacanthus*, and three of *Rhizodus*, have been described by Newberry from Linton. Other Ganoids occur, of the genera *Megalichthys, Palæoniscus, Amblypterus*, and *Pygopterus*, in the Coal measures of the United States and Nova Scotia.

Among *Selachians*, the following European genera have been recognized in the Coal-measure limestones of Pennsylvania, Ohio, Indiana, Illinois, etc., — the species being generally distinct from those of the Old World: 1. HYBODONTS: genera *Diplodus* and *Cladodus; Diplodus compressus* Newb., Linton, Ohio; *D. latus* Newb., ibid.; *D. gracilis* Newb., ibid.; 2. PETALODONTS: genera *Petalodus, Ctenoptychius, Chomatodus;* Fig. 675, *Petalodus destructor* N. & W., from Illinois; 677 *a*, 677 *b*, *Petrodus occidentalis* N. & W. from Illinois, Indiana, etc.; 676, fin-spine found associated with the scales of *Petrodus occidentalis*, and referred by F. H. Bradley to the same species. Also *Orthacanthus arcuatus* Newb., Linton; *Compsacanthus levis* Newb., Linton; *Drepanacanthus anceps* N. & W., from Springfield, Illinois.

(*b.*) *Reptiles.* — *Amphibians.* — Fig. 679, *Raniceps Lyellii* Wyman, found by Dr. Newberry, along with fossil fishes, at Linton, Ohio: Fig. 678, *Amphibamus grandiceps* Cope, from Morris, Illinois; Fig. 680, vertebræ and ribs, of a species figured by Wyman, but not named, from Linton, Ohio. *Baphetes planiceps* Owen, from Pictou, Nova Scotia; the specimen is a portion of the skull, seven inches broad; *Dendrerpeton Acadianum*, found in the stump of a *Sigillaria* at the Joggins (p. 339), probably about two and a half feet long, and having the body covered with scales, and the whole surface of the cranium sculptured; *D. Oweni* Dn., ibid.; *Hylonomus Lyelli* Dn., ibid.; *H. aciedentatus* Dn., ibid.; *H. Wymani* Dn., ibid.; *Hylerpeton Dawsoni* Owen, ibid.

Amphibian footprints have been observed in the Coal-measures of Pennsylvania, Kansas, Indiana, and Nova Scotia. Near Westmoreland, Pa., in a layer situated about 100 feet below the horizon of the Pittsburg coal, Dr. A. T. King counted twenty-three consecutive steps of one individual, which he named *Thenaropus heterodactylus;* the tracks of the hind-feet five-toed, and of the fore feet four-toed, — the former five and a half inches long, and the latter four and a half inches; and the distance between the successive tracks six to eight inches, and between the two lines about the same. Another species from the same region is the *Cheirotherium Reiteri* of Moore.

Enaliosaurs. — Fig. 681, vertebra of *Eosaurus Acadianus* Marsh, reduced to one half the natural size, being one of two united vertebræ found by Marsh at the Joggins, Nova Scotia, 5,000 feet below the top of the Coal-measure series; 681 *a*, transverse section of same, showing its biconcave character. The resemblance to the vertebra of an *Ichthyosaurus* (Fig. 807, p. 442), is close; and, from the depth of its concavities, the animal is supposed by Marsh to have been one of the most fish-like of the tribe. Huxley has suggested, in view of the characters of the *Anthracosaurus Russelli* of the British Coal fields, described by him, that the animal may have been a Labyrinthodont with biconcave vertebræ. Marsh has given reasons for holding to his first opinion that the species was an Enaliosaur.

2. Coal-measures of Foreign Countries.

I. Distribution of the Coal-measures.

The Coal-formation in Europe has great thickness of rocks and coal in Great Britain, much less in Spain, France, and Germany, and

Fig. 681 A.

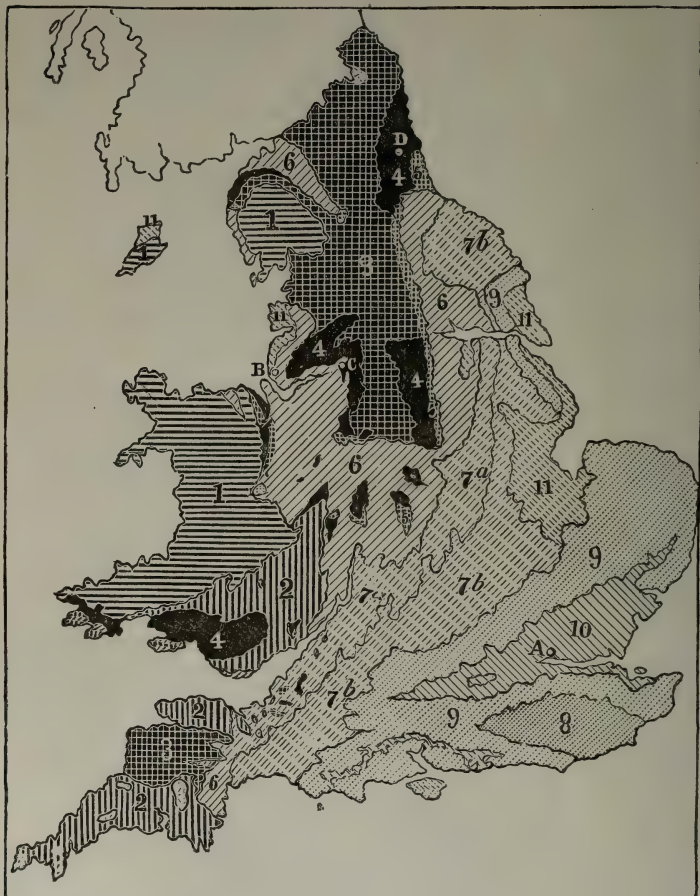


Fig. 681 A, Geological Map of England. The areas lined horizontally and numbered 1 are Silurian. Those lined vertically (2), Devonian. Those cross-lined (3), Subcarboniferous. Carboniferous (4), black. Permian (5). Those lined obliquely from right to left, Triassic (6), Lias (7 *a*), Oölyte (7 *b*), Wealden (8), Cretaceous (9). Those lined obliquely from left to right (10, 11), Tertiary. A is London, B, Liverpool, C, Manchester, D, Newcastle.

a large surface, with little thickness or coal in Russia. It exists, also,

and includes workable coal-beds, in China, and also in India and Australia; but part of the formation in these latter regions may prove to be Permian. No coal of this era has yet been found in South America, Africa, or Asiatic Russia.

The proportion of coal-beds to area in different parts of Europe has been stated as follows: in France, 1–100th of the surface; in Spain, 1–50th; in Belgium, 1–20th; in Great Britain, 1–10th. But, while the coal-area in Great Britain is about 12,000 square miles, that of Spain is 4,000, that of France about 2,000, and that of Belgium 518.

The distribution of the Coal-measures over England is shown on the accompanying map, the black areas, numbered 4, representing them. The Coal-measures appear over a broad region running north-northeast across from South Wales to the northeast coast, where is the Newcastle basin. The principal regions are the South Wales, 600,000 acres in area, and, in nearly the same latitude, the Forest of Dean, west of the Severn, and the region about Bristol, east of the Severn; the small patches in central England, in Worcestershire, Shropshire (Coalbrook Dale), Warwickshire, Leicestershire, and Staffordshire; north of these, the great Lancashire region, east of Liverpool, with the basin of Flintshire on the Dee, the whole together over 500,000 acres; a little to the east, the Derbyshire coal region, between Nottingham and Leeds, and adjoining Sheffield (covering parts of Nottinghamshire, Derbyshire, and Yorkshire), 550,000 acres in area; farther north, a patch on the western coast, in Cumberland, about Whitehaven, etc.; and, on the eastern coast, the great region of Newcastle, 500,000 acres in area.

In Scotland, the beds cover an area of about two thousand square miles, and lie between the Grampian range on the north and the Lammermuirs on the south.

In Ireland, there are several large coal-regions, — that of Ulster, to the north, estimated at 500,000 acres; of Connaught, also in the north, 200,000; of Leinster (Kilkenny), in the southeast, 150,000; of Munster, on the west, south of Galway Bay, 1,000,000.

Ramsay observes that all the coal-areas of England were once one great coal-field; in other words, that they were made in one continuous area of marshes and inland lakes. He also thinks it probable that the coal-area of the lowlands of Scotland was originally part of the same great basin.

The first stratum in the Carboniferous series, over the Subcarboniferous, is the Millstone-grit, — as in Pennsylvania.

In South Wales, the thickness of the Coal-measures is 7,000 to 12,000 feet, with more than one hundred coal-beds, seventy of which are worked: that of the Millstone-grit is 400 to 1,000 feet.

In the Forest-of-Dean, the Coal-measures have a thickness of 2,400 feet, and include at least twenty-three coal-beds, and the Millstone-grit 455 feet: while in the Bristol coal-field, the other side of the Severn, there are 5,090 feet of Coal-measures, with eighty-seven coal-beds, according to Prestwich; but a middle portion, called the Pennant series, 1,725 feet thick, consists largely of sandstone, and contains only five coal-beds. Below, there are nearly 1,000 feet of Millstone-grit, which is partly red sandstone.

In the Lancashire Coal-region, which reaches nearly to Liverpool, the Coal-measures are stated to have a thickness of 7,200 feet, and to include over forty beds of coal over one foot in thickness, and the Millstone-grit of 3,500 to 5,500 feet.

The Lancashire area, and the Cumberland, farther north, lie on the *west* side of an anticlinal ridge, mostly of Subcarboniferous and Lower Carboniferous rocks, called the Pennine chain, in some points 2,000 feet high, which extends north to the Cheviot Hills, between England and Scotland. The Derbyshire and Newcastle areas are to the *east* of this anticlinal. In the former, the thickness of the Coal-measures is less than 4,000 feet, of which nineteen beds are of coal, and that of the Millstone-grit is about 350 feet. In the latter, the Coal-measures are about 2,000 feet thick, and include about sixty feet of coal, and the Millstone-grit is a little over 400 feet thick: the beds afford about a fourth of the coal of England.

In the south of Ireland, the Coal-measures contain 300 feet of Lower shales, 500 of the flagstone series, and 1,800 of shales, sandstones, etc., with coal; and, in the north of England, there are 500 feet of Millstone grit, beneath 2,000 of Coal-measures.

Ramsay has stated that, under Permian and Triassic strata, north of the Bristol coal-field, there may probably be about 55,000 millions of tons of coals available, at all events at less than 4,000 feet in depth; and to this Mr. Prestwich has added 400 millions of tons for the Severn valley, on the south side of the estuary.

The coal-workings are carried on in most of the British mines by a regular system of deep mining. At Whitehaven, the mines reach out far under the sea. All coal-beds, a foot thick and within 4,000 feet of the surface, are regarded by Ramsay as economically workable; and, on this as a basis, he calculates that the amount of coal available is 80,000,000,000 of tons. In 1870, 110,000,000 tons of coal were raised.

It is believed, with apparently good reason, that the Coal-measures, with their many coal-beds, may exist beneath the region of Permian rocks numbered 6 in the map on page 344, and perhaps farther to the southeastward.

The coal of England, Scotland, and Ireland is mainly bituminous or semi-bituminous. Anthracite occurs in South Wales, especially its western part, and also in the mines of southern Ireland (Cork, Kerry, Limerick, and Clare); but this variety is in general less hard and more inflammable than that of Pennsylvania.

The following are the principal coal-mines of the countries of Europe: —

France. — Basin of the Loire (St. Etienne); containing eighteen beds of bituminous coal, and also some anthracite; Moselle (Saarbrück); Burgundy; Languedoc; Provence; Limousin; Auvergne; Brittany.

Belgium. — Liège Coal-field, — the eastern division, about 100,000 acres; Hainault Coal-field, — the western division, 200,000 acres.

Germany. — Basin of the Saar, tributary to the Moselle, on the borders of France (the Saarbrück Coal-field); Basin of the Ruhr, tributary to the Rhine, near Dusseldorf (Dortmund and Westphalian Coal-fields), — the eastern extension of the Belgian region. In Saxony, near Zwickau and Dresden.

Austria. — Bohemia, south of the Erzgebirge and Riesengebirge, and reaching into Silesia.

Spain. — In the Asturias (largest); near Cordova; Catalonia (small).

Portugal. — Near Coimbra.

Russia. — The Millstone-grit, according to Murchison, occurs along the west flank of the Ural, and to the southward in the region of Donetz, where there is some coal. But the great Carboniferous area of Russia is mainly a region of Subcarboniferous limestone; and the true Coal-measures are almost wholly wanting beneath the wide-spread Permian beds. The Permian, Carboniferous, Devonian, and Silurian beds, which are spread out nearly horizontally over the vast Russian plains, are folded up in the Urals and partly metamorphosed, the making of these mountains having taken place after the Permian era.

Prestwich observes, with regard to a close parallelism in the several coal-beds, between the different British coal-fields, and between these and European coal-fields, that, while this is not to be looked for, some general relations may be made out. The great dividing mass of rock, 2,000 to 3,000 feet thick, called *Pennant*, exists in both the Welsh and Bristol coal-fields; and the total thickness is not very different in the two — about 10,500 feet in one and 8,500 in the other, with seventy-six coal-beds in Wales, and fifty-five in Somerset. In the Hainault (or Mons and Charleroi) basin, the measures are 9,400 feet thick, with one hundred beds of coal; in the Liège basin, 7,600 feet, with eighty-five beds; in Westphalia, 7,200 feet, with one hundred and seventeen beds. Prestwich adds, further, that the earliest British coal-beds are to the north, where they occur low down in the Subcarboniferous limestone; but there the later are wanting; while to the south, coal-beds appear first above the Millstone-grit, and the making of coal-bed debris continued long after it had ceased to the north. Moreover, in Britain, the northern Coal-measures, excepting the Lanarkshire, are not half the thickness of the southern, and for the most part hardly one-fourth.

II. Life.

1. *Plants.*

The same genera of plants are represented among the European coal-beds as occur in America; and very many of the species are identical. In this respect, the vegetable and animal kingdoms are in strong contrast; for the species of animals common to the two continents have always been few.

The following table contains the number of species of the different genera of coal-plants peculiar to each continent, North America and Europe (Britain included), and, in another column, those common to both.

Genera of Coal-Plants.	Species peculiar to the United States.	Species peculiar to Europe.	Species common to both Continents.
I. Equisetites *Sternb.*	4	3	1
Calamites *Suck.*	1		6
Asterophyllites *Brngt.* (Calamocladus *Schp.*)	3		5
Calamostachys *Schp.*	1	3	3
Huttonia *Sternb.*		1	
Macrostachys *Schp.*			1
Bornia *Röm.*	1	1	1
Sphenophyllum *Brngt.*	2		6
Annularia *Brngt.*	2		4
II. Sphenopteris *Brngt.*	14	48	22
Eremopteris *Schp.*			1
Steffensia *Göpp.*			1
Adiantites *Göpp.*		5	1
Neuropteris *Brngt.*	20	8	16
Odontopteris *Brngt.*	9	3	6
Lescuropteris *Schp.*	1		
Callipteris *Brngt.*	1	2	
Cyclopteris *Göpp.* (Palæopteris *Schp.*, Nœggerathia *Lsqx.*)	5	2	3
Triphyllopteris *Schp.*		1	
Rhacopteris *Schp.*		1	
Pecopteris *Brngt.*	15	37	25
Goniopteris *Presl.*		1	5
Phyllopteris *Dn.*	1		
Alethopteris *Sternb.*	10	5	5
Neriopteris *Newb.*	1		
Beinertia *Göpp.*	1	1	
Staphylopteris *Presl.*	5		
Asterocarpus *Göpp.*	1	1	1
Oligocarpia *Göpp.*			1
Hawlea *Corda*		1	
Dictyopteris *Gutb.*	2	3	1
Lonchopteris *Brngt.*	1	5	
Schizopteris *Brngt.*			1
Rhacophyllum *Schp.*	5	1	5
Pachypteris *Brngt.*	1		
Rhizomopteris *Schp.* (Stigmarioides *Lsqx.*)	8		2
Caulopteris *L. & H.*		3	
Stemmatopteris *Corda*	5		2
Megaphytum *Art.*	4	4	
Psaronius[1] *Cotta*	10?	2	
III. Lycopodites *Auct.*	3	8	1
Lepidodendron *Sternb.*	21	30	7
Ulodendron *Rhode*	1	6	2
Knorria *Sternb.*			2
Lepidophloios *Sternb.*	8	3	1
Halonia *L. & H.*	1	6	1
Cyclocladia *Goldenb.*		1	
Lepidostrobus *Brngt.*	14	9	4
Lepidophyllum *Brngt.*	7	1	4
Schutzia *Göpp.*	1		
Antholithes *L. & H.*	5	3	
Psilophyton *Dn.*	1		
Psilotites *Goldenb.*		1	
Sigillaria *Brngt.*	18	44	23
Sigillarioides *Lsqx.*	2		
Stigmaria *Brngt.*	6		3
Pinnularia *L. & H.*	7		1

[1] American species are not as yet positively studied: from specimens collected in large numbers ten to fifteen species are recognized (not described). (Lesquereux.)

Genera of Coal Plants.	Species peculiar to the United States.	Species peculiar to Europe.	Species common to both Continents.
Diploxylon *Corda* . . .	1	2	
IV. Nœggerathia *Sternb.* . .	1	4	1
Whittleseya *Newb.* . . .	1		
Cordaites *Ung.* (Pycnophyllum *Brngt.*, Flabellaria *Sternb.*) .	3	1	2
Trigonocarpus *Brngt.* . . .	16	4	7
Rhabdocarpus *Göpp. & Berg.* .	10	11	5
Cardiocarpus *Brngt.* . . .	13	3	1
Ptilocarpus *Lsqx.* . . .	3		
Carpolithus *Sternb.* . . .	14	4	1
Polysporia *Newb.* . . .	1		
Walchia *Sternb.*	2		
Araucaroxylon *Kraus* (Dadoxylon *Endlinger*)	3	10	
V. Spirangium *Schp.* (Palæoxyris *Brngt.*)	3	1	

The genera *Calamites*, *Sphenopteris*, *Pecopteris*, *Lepidodendron*, and *Sigillaria* have much the largest number of species in Europe.

According to this table, — for which the work is indebted to Professor L. Lesquereux, — there are in all, exclusive of fruits, about four hundred and thirty-four known American species, and four hundred and forty European (and British); and, of these, one hundred and seventy-six are common to the two continents. In other words, about *two fifths* of all the American species were growing also in the Carboniferous forests of the other continent.

The type of Cycads was represented in Europe by pinnate leaves of Mesozoic genera. Geinitz has described one species, near *Pterophyllum inflexum* Eichw., as occurring near Barnaoul, in the Altai, along with the Carboniferous plants, *Lepidodendron Serlii* Brngt., *Nœggerathia æqualis* Göpp., *N. distans* Göpp., *Sphenopteris anthriscifolia* Göpp., etc. He proposes for it the name *Pt. Altaense.* Another related *Pterophyllum* has been announced by Sandberger as found in the Upper Carboniferous rocks of the Schwarzwald, in Baden, Germany.

2. *Animals.*

The most important additions to the facts already stated, furnished by the European rocks, are those relating to the classes of Insects and Spiders. Besides *Cockroaches*, there were probably *Weevils*, as well as other kinds of Beetles, species related to the *May-fly* and *Dragon-fly*, and also to *Termites.* The class of Spiders (or Arachnidæ) was represented by *Scorpions*, *Pseudo-scorpions*, and true Spiders, as in America.

The Vertebrates were similar in type to the American, the fishes being *Ganoids* and *Selachians*, and the Amphibians mainly *Labyrinthodonts*, with few Reptiles.

A number of European Subcarboniferous species are identical with, or closely related to, forms common in the American Coal-measures. Thus it is with the following:

Athyris subtilita, *Retzia radians* Morr., *Spirifer lineatus*, *S. Urii* Flem., *Productus longispinus* Sow., *P. scabriculus* Sow., *P. costatus* Sow., *Fusulina cylindrica*, and *F. robusta*.

The following figures represent some of the remains of *Articulates:* (*a.*) *Crustaceans*, — No species of Trilobites are reported from the foreign Coal-measures, — showing, apparently, the complete extinction of this ancient tribe. Fig. 683, *Prestwichia rotundata* Woodw., reduced one half, Coalbrook Dale; *P. anthrax* Woodw., Coalbrook Dale; *Belinurus trilobitoides* Woodw., Ireland and Coalbrook Dale; *B. reginæ* Baily, Ireland; *B. arcuatus* Baily, Ireland. Fig. 682, *Gampsonyx* (*Euronectes*) *fimbriatus* Jordan, a *Schizopod.* Fig. 686 A, *Anthrapalæmon Salteri*, from Lanarkshire, Scotland. *A. dubius* S. and *A. Grossarti* S. are other species referred to this genus, the former from Coalbrook Dale (includes the *Glyphea* (?) *dubia* S., and *Apus dubius* M.-Edw.), and the latter from Lanarkshire; but the broad flattened carapax indicates a nearer relation to *Æglea* and *Galathea* than to *Palæmon*. *Pygocephalus Couperi* Hux. is the name of a Schizopod from near Manchester, England.

Figs. 682–686.

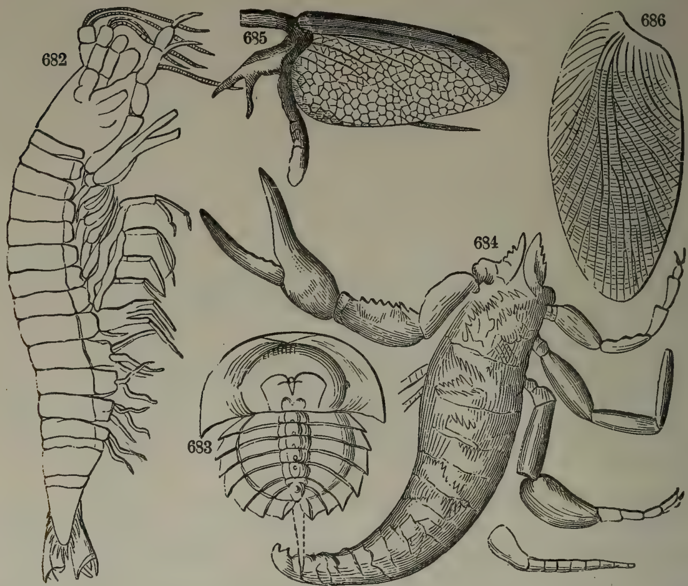
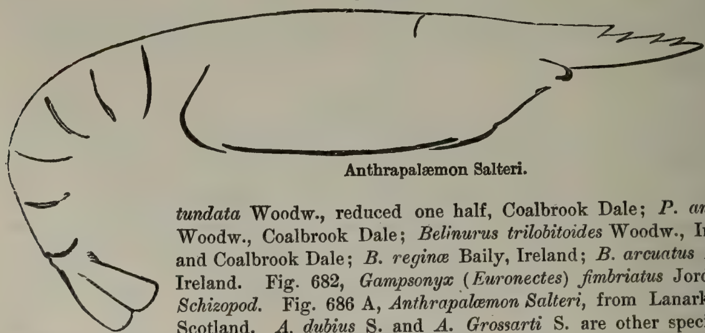


Fig. 682, Gampsonyx fimbriatus; 683, Prestwichia rotundata (×½); 684, Cyclophthalmus senior; 685, Dictyoneura anthracophila; 686, Blattina primæva.

Fig. 686 A.



Anthrapalæmon Salteri.

(*b.*) *Myriapods.* — *Euphoberia Brownii* Woodw., from Glasgow, *E. anthrax* Woodw., from Coalbrook Dale, *Xylobius sigillariæ* Dn., from Glasgow and Huddersfield.

(*c.*) *Spiders.* — (1.) Scorpions: Fig. 684, *Cyclophthalmus senior* Corda, a Scorpion from Chomle, Bohemia. (2.) Pseudo-scorpions: *Microlabis Sternbergi* Corda, from Bohemia. *Eophrymus Prestwitchii* Woodw., from Dudley; *Architarbus subovalis* Woodw., Lancashire, very near the Illinois species (p. 342). (3.) True Spiders: *Protolycosa anthracophila* R., from Silesia; an *Aranea*, from Bohemia.

(*d.*) *Insects.* — Remains of Insects have been found at several localities, and especially at Saarbrück and Wettin. (1.) Neuropters: *Dictyoneura anthracophila* Goldb., Saarbrück; *D. Humboldtiana* Goldb., ib.; *D. libelluloides* Goldb., ib.; *Corydalis Brongniarti* Mant., Coalbrook Dale. (2.) Orthopters: Fig. 686, *Blattina primæva* Goldb., Saarbrück, besides two other *Blattinæ* from Saarbrück, and several from Westphalia; *Gryllacris lithanthraca* Goldb. (Locust), from Saarbrück; *Termes Heeri* Goldb., and other species, from Saarbrück. (3.) Coleopters: *Troxites Germari* Goldb., Saarbrück; *Curculioides Ansticii* Buckl., Coalbrook Dale.

(*e.*) *Fishes.* — The Fishes of the Carboniferous age are found most abundantly in the Subcarboniferous limestones, as these were wholly of marine origin; still, a considerable number of species occur in the Coal-measures. The Selachians are of the genera *Ctenodus, Ctenoptychius, Gyracanthus*, etc., and also *Helodus, Cladodus, Orodus, Ctenacanthus*, etc., which are mostly Subcarboniferous. The most common Coal-measure genera of Ganoids are *Palæoniscus, Amblypterus*, and *Holoptychius*.

(*f.*) *Amphibians.* — A few Amphibian remains have been observed in Europe and Britain, similar in character to those of America, indicating the existence of Labyrinthodonts. *Loxomma Allmanni* Hux., Edinburgh, the skull ten inches wide and fourteen long; *Anthracosaurus Russelli* Hux., Lanarkshire; *Parabatrachus Colei* Owen, British Coal-measures; *Anthracerpeton crassosteum* Owen, Glamorganshire; *Archegosaurus Decheni* Goldfuss, Saarbrück, three and one-half feet long; *A. minor* Meyer, Saarbrück; *Apateon pedestris* H. v. Meyer, from near Münsterappel, on the Bavarian Rhine; *Urocordylus Wandesfordii* Hux., Kilkenny, the tail very long, having seventy-five vertebræ; *Ophiderpeton Brownriggii* Hux., Kilkenny, snake-like, three feet long; *Septerpeton Dobbsii* Hux., Kilkenny.

3. General Observations.

1. Source of Coal. — (1.) *Coal derived from Vegetation.* — As the coal-beds and accompanying strata abound in the impressions of leaves and stems, and the coal also consists largely of vegetable fibre (p. 318), the vegetable origin of coal is beyond all reasonable doubt.

(2.) *Plants of the Coal.* — The plants that have contributed most to the formation of the great beds of vegetable debris, which were afterward converted into coal, are the *Sigillarids*, *Calamites*, *Ferns*, and *Cordaites*, with the *Lepidodendrids* for the beds of the Lower Coal-measures.

The *Sigillarids* and *Calamites* were probably for the most part confined to the wet grounds or marshes, and the islands of floating plants; while the *Lepidodendrids* and *Tree-ferns*, judging from recent Lycopods and Ferns, were plants both of the wet plains and of the dry hills. Conifers must have been associated with these last in the drier forests of the continent; but, if the *Cordaites* are the leaves of any of the species, they also spread over the wet regions, and took part in the construction of the floating islands. The nature of the plants found in the coal-beds, and of the associated animal life, is proof that the coal is not made even partly of marine species.

2. Climate, Atmosphere. — The growth of the Carboniferous vegetation was dependent, as now, on the climate and the condition of the atmosphere.

(1.) *Temperature of the Ocean and Air.* — In the animal life of the waters, we have a safe criterion for the temperature of the oceans. Among the species, there was the large coral, *Lithostrotion*, common in both Europe and the United States. One such species is almost sufficient to prove a similar temperature for the ocean over these two distant regions. This *Lithostrotion* was found by Beechey on the northwest Arctic coast, between Point Barrow and Kotzebue Sound; and with it occurred other corals, and, among the Brachiopods, *Productus semireticulatus*, well known in lower latitudes. The Arctic was, therefore, at that time a reef-growing sea; and, if the distribution of corals, forming coral-reefs, was limited by the same temperature then as now, the waters were at no part of the year below 66° F. Besides the above species, there have been identified, in the Arctic, the European species *Productus sulcatus* Sow., *Atrypa aspera* Dalm., *A. fallax* Sow. These were found on Bathurst and the neighboring islands, in latitudes 75° and 77°.

The small diversity in the oceanic temperature of the globe is further shown by the occurrence of the following Carboniferous species in the Bolivian Andes: *Productus semireticulatus*, *P. longispinus* Sow., *Athyris subtilita*, and a *Bellerophon*, resembling *B. Urii* Flem.

The coal-beds of Arctic regions are evidence of a profuse growth of vegetation over an extended area, and protracted through a long period. The conditions, between the latitudes 70° and 78°, were, therefore, analogous to those over the United States, from Pennsylvania to Alabama, and from Illinois to Texas. While a general resemblance to the ancient flora of the United States and Europe is apparent from the observations which have been made, but few species have yet been identified. The plants were not mosses of peat swamps, such as now extend far north. If we draw any conclusion from the facts, it must be that the temperature of the Arctic zone differed but little from that of Europe and America. Through the whole hemisphere — and, we may say, world — there was a genial atmosphere for one uniform type of vegetation, and there were genial waters for Corals and Brachiopods.

(2.) *Moisture of the Atmosphere.* — A warm state of the globe would necessarily imply a very much larger amount of evaporation than now. The climate would be insular throughout; and heavy mists would rest over the land, making the air and land moist. The comparatively small diversity of climate between the equator and poles would probably be attended with fewer storms than now, and with a less rapid movement in the general circulation.

(3.) *Impurity of the Atmosphere.* — In the present era, the atmosphere consists essentially of oxygen and nitrogen, in the proportion of 23 to 77 parts by volume. Along with these constituents, there are about four parts by volume of carbonic acid, in 10,000 parts of air. Much more carbonic acid would be injurious to animal life. To vegetable life, on the contrary, it would be, within certain limits, promotive of growth; for plants live mainly by means of the carbonic acid they receive through their leaves. The carbon they contain comes principally from the air.

This being so, it follows, as has been well argued, that the carbon which is now coal, and was once in plants of different kinds, has come from the atmosphere, and, therefore, that the atmosphere now contains less carbonic acid than it did at the beginning of the Carboniferous period, by the amount stowed away in the coal of the globe.

Volcanoes contribute at the present time a little to the carbonic acid of the atmosphere; and it may be that some of the carbon in coal is from this source. But this carbonic acid is given out only where the heat of the volcanic vent has limestone to act upon; and, if this is a rare case now, it was even less common in Paleozoic time, when volcanoes were probably far less numerous. Moreover, the carbon in the limestone (carbonate of lime) of the globe, while it was taken directly from the earth's waters (p. 130), came in part from the atmosphere, the rains carrying it down to the ocean. If, then, the limestones robbed the atmosphere, as well as the coal, the amount of Carboniferous coal in the earth's rocks does not probably represent more carbonic acid than the atmosphere of the Carboniferous age lost.

Such an atmosphere, containing an excess of carbonic acid as well as of moisture, would have had greater density than the present; consequently, as urged by E. B. Hunt, it would have occasioned increased heat at the earth's surface, and this would have been one cause of a higher temperature over the globe than the present.

During the progress of the Carboniferous period there was, then, (1) a using up and storing away of the carbon of the superfluous carbonic acid, and, thereby, (2) a more or less perfect purification of the atmosphere, and a diminution of its density. In early time, there was no aërial animal life on the earth; and, so late as the Carboniferous period, there were only Reptiles, Myriapods, Spiders, Insects, and pulmonate Mollusks. The cold-blooded Reptiles, of low order of vital activity, correspond with these conditions of the atmosphere. The after-ages show an increasing elevation of grade and variety of type in the living species of the land.

(4.) *Influence of the Climate on the Growth of Plants.* — A moist warm climate produces exuberant growth in plants that are fitted for it. The plants of the Coal period were made for the period. The *Sigillarids* and *Calamites* manifest, by their characters and mode of occurrence, that they could flourish only in a moist region; and the

Ferns of the tropics are most luxuriant in moist woods. The *Lepidodendrids*, by their association with the *Sigillarids* and *Ferns*, show that the same conditions (as is now the case with their kin, the Lycopodia) favored their development. In fact, Lycopods, Equiseta, and most Ferns, are plants that like shady as well as moist places. Adding, then, the prevalent moisture and warmth to the excess of carbonic acid in the atmosphere, we should be warranted in concluding that, even if there were less sunshine than at the present time, vegetable growth must have been more exuberant than it is now, especially in the colder temperate zones. This exuberance would not have shown itself in thick rings of growth, in trees made for those very conditions, but, as through the existing tropics under a moist climate, in the great denseness of the jungles and forests, many plants starting up where but one would have flourished under less favorable circumstances. Our peat swamps are often referred to, as a measure for the growth of plants in the Coal era. But while they illustrate well the mode of making beds of vegetable debris, their rate of progress may be no safe criterion as to the rate in Carboniferous swamps. The peat-plants of the present day are species of the temperate and colder zones, and are too different in kind to warrant a comparison.

3. Geographical Conditions over North America, during the Progress of the Carboniferous Period. — The Subcarboniferous was a period of *submerged* continental regions; and the Carboniferous of as extensive an *emergence;* not continuous emergence, but prolonged and repeated emergences with little change of level, alternating with slight or partial subsidences.

The conglomerate, called *Millstone-grit*, with whose formation the Coal-period began, marks the transition from the marine to the terrestrial period. The area that had been covered with fields of Crinoids was swept during this epoch by currents and waves, which left the surface under a great depth of pebbles and sand. The coarseness of the beds along the Appalachian region, in Pennsylvania, points out that this was the border-reef of the continent; and the great thickness of the deposits, — 1,100 feet, — that it was a region also of profound, though slowly progressing, subsidence. The more sandy character of the beds of this border in Virginia harmonizes with the general fact in earlier time; and so also do the little thickness and finer character of the beds of Ohio and eastern Kentucky, — a region on the inner margin of the subsiding Appalachian era, not participating so fully in the great change of level.

The coal-beds of the Millstone-grit also show that the continent was in this semi-emerged condition; for every such bed is proof that areas of land were, for a long time, above the ocean, where plants could grow.

When the *era of the Coal-measures* had fairly set in, the great Interior region of the Continent, even from the eastern limits of the Appalachian region to the western borders of Kansas and Nebraska, as the extent of the Coal-formation shows, slowly emerged; and the continent then, for the first time, extended from the remote Arctic zone, south to Alabama. West of Kansas, there were limestones of the Coal-measure era in progress, instead of coal-beds; and these indicate that the old sea of the Interior region still covered the slopes and summits of the Rocky Mountains; and over these meridians the waters may have connected with the Arctic ocean. The limestones of Point Barrow, at the farther extremity of the Rocky Mountain range, may be of the same age.

This emergence, giving so great extent to the young continent, was not complete until the first of the great beds of vegetable debris began to form. Then North America, within the limits stated, was one vast forest, except where fresh waters lay too deep for forests to grow; and the lakes probably had islands of shrubbery and forest vegetation floating over the waters, as is now true of some of the tropical lakes of India.

Since single coal-beds in the earlier part of the series appear to have had a very wide range, it is safe to conclude that the great Interior region had nearly a common level, — that it was a vast plain, with, at the most, only gentle undulations in the surface, and with the higher land mainly over the Archæan and Silurian lands to the north. There were no Alleghanies; for this very region was a part of the great coal-making plain: there were no Rocky Mountains, for these, as the Carboniferous limestones prove, were mainly under the sea. The Appalachian region and the Interior basin, both east and west of the Mississippi, were merged in one great continental basin, all making together one nearly level country, the low Cincinnati ridge being the only land west of New York that projected above the level of the marshes. Being thus level, there could have been no great Mississippi or Ohio; the continent would have had no sufficient drainage, and the wide plains would necessarily have been marshy, and spotted with shallow lakes.

This Continental basin, as stated on page 146, was separated from the Eastern-border region, by the Green Mountains, — a range which had stood as a low barrier between New England and New York, from the close of the Lower Silurian. Both the Nova Scotia Coal-measures and those of central Pennsylvania are almost destitute of true marine fossils; and hence the true raised border of the continent was some miles, or scores of miles, to the eastward of the most eastern Carboniferous limits. The Nova Scotia and New Brunswick beds

were laid down in a great estuary constituting the mouth of the St. Lawrence, then the greatest river of the continent; and this estuary appears to have spread southward along the Bay of Fundy, and northward and northeastward, over the St. Lawrence bay, to Newfoundland; for the coal-rocks cover even the extreme northern portion of the peninsula of Nova Scotia. Hence the raised continental border in this part probably lay as far out as eastern Newfoundland, from which it may have stretched far enough southwestward to have shut in also the Rhode Island region. The dip of the Nova Scotia Coal-beds, and their great thickness at Pictou, on the shores of the Gulf, show that only a small part of the originally great area is now above the sea-level.

Over these marshes, then, grew the clumsy *Sigillarids* and *Calamites*, and the more graceful *Tree-ferns*, *Lepidodendrids*, and *Conifers*, with an undergrowth of *Ferns*, and upon the dry slopes near by, forests of *Lepidodendrids*, *Conifers*, and *Tree-ferns;* and the luxuriant growth was prolonged until the creeping centuries had piled up vegetable debris enough for a coal-bed. Trees and shrubs were expanding, and shedding their leaves and fruit, and dying, making the accumulation of vegetable remains. Islands of vegetation, floating over the lakes, may have contributed largely to the vegetable debris. Stumps stood and decayed in the swamps, while the debris of the growing vegetation, or, in some cases, the detritus borne by the waters, accumulated around them; and their hollow interiors received sands, or leaves, or bones, or became the haunts of reptiles, as was their chance. Logs were floated off over the lakes, to sink and become buried in the accumulating vegetable debris, or in deposits of detritus; and some of these transported stumps may have had aboard large stones, which they finally dropped, and so put an occasional "bowlder" into the forming beds.

As already explained, there is no reason to suppose that the vegetation was confined to the lower lands: it probably spread over the whole continent, to its most northern limits. It formed coal only where there were marshes, and where the deposits of vegetable debris afterward became covered by deposits of sand, clay, or other rock-material.

The condition of the continent just described represents only one phase in the Carboniferous period. The rocks register a succession of changes; for coal-beds are succeeded by sandstones, or shales, or limestones, or iron-ore beds, and many alternations of these beds, to a thickness fifty times as great as that of the coal-beds. These intervening strata, moreover, were sometimes of fresh-water origin; and at others, of marine: in the one case, containing fresh-water shells, or

other inland species; in the other, full of Crinoids and Brachiopods, the life of the sea. The great extent of the continent, wherever these strata occur, underwent, therefore, continued oscillations of level, or the sea as unceasing changes of water-level. After a period of verdure, there followed a desolation as complete as that when the subjacent Millstone-grit was spread over the surface, — either a subsidence of the interior, or some other change, that led to a general submergence beneath *fresh-waters*, or a similar subsidence, or else a removal or sinking of barriers, that placed the whole beneath *salt water;* in either case, the former vegetation gave way to aquatic life again.

The broken relics, that were a result of the catastrophe, are often packed together in the first deposits that ensued. Lesquereux states that, in the roof-shale of the coal-bed at Carbondale, Pa., there was found an impression of the bark of a *Lepidodendron*, two feet wide and *seventy-five feet* in length. Andrews mentions that thousands of the trunks of the Fern, *Pecopteris arborescens* Lsqx., are found in the shale over the Pomeroy Coal-bed; and that at one place the trunk of a *Sigillaria* was traced by him for more than forty feet.

The oscillations must have been exceedingly various, to have produced all the alternations of shales, sandstones, limestones, and ore-beds.

The movements, moreover, must have been slow in progress: motion by the few inches a century accords best with the facts. When under terrestrial vegetation, and receiving vegetable debris for coal-beds, it must have lain for a long period almost without motion; for only a very small change of level would have let in the salt water to extinguish the life of the forests and jungles, or have so raised the land as to dry up its lakes and marshes. Hence the grand feature of the period was its prolonged eras of quiet, with the land little above the sea-limit, — a condition that made coal-beds also in later geological ages. Again, for the making of the shales or sandstones, the continent may have rested long near the water's surface, just swept by the waves. It may have been long a region of barren marshes; and, in this condition, it might have received its iron-ore deposits, as now marshes become occupied by bog-ores. It must have been long in somewhat deeper waters, and covered with a luxuriance of marine life, in order to have received its beds of limestone. Finally the land slowly emerged again from the waters, and the old vegetation spread rapidly across the great plains, commencing a new era of coal-making vegetable debris; or the escape was only partial, and coal-plants took possession of one part, and made limited coal deposits, while the sea still held the rest beneath it; for uniform oscillations of level in all cases, through so great an area, are not probable; and

therefore the former continuity of a single coal-bed through the East and West requires strong proof, to be admitted.

The coal-beds are thin, compared with the associated rocks. But the time of their accumulation, or the length of all the periods of verdure together, may have far exceeded the time that was given up to the accumulation of sands and limestones. If there were but 100 feet of coal in all, it would correspond to between 500 and 1000 feet in depth of vegetable debris. The sands and clays came in after each time of verdure, to store away the product for a future age.

These submergences, although quietly carried forward, sometimes let in currents or waves of great force, as shown not only by the formation of coarse gravel beds (now conglomerates), but also by the erosion of the rock-deposits, and also of the beds of vegetable debris. In Vermilion County, Illinois, as observed by F. H. Bradley, a portion of the Upper Coal-measures, including shales, argillaceous limestones, and two coal-beds, were carried away to a depth of sixty feet; and, in the depression thus made, a sandstone, which belongs at the top of the series, was laid down so as to fill and overlie it. Also, on the same authority, in Vermillion County, Indiana (adjoining the county just mentioned), the Millstone-grit (here a pebbly sandstone), under the Coal-measures, is cut off short, and followed horizontally by shale and limestone; as if the grit stood as a bluff in the waters, in which the latter rocks were deposited. Other evidences of erosion have been described from these States, and also from Ohio.

In Nova Scotia, the changes during the Carboniferous period (or Carboniferous and Permian) went on until 14,570 feet of deposits were formed; and, in that space, as has been stated, there are seventy-six coal-seams and dirt-beds, indicating as many levels of verdant fields, between the others when the waters prevailed. In Pennsylvania, there are nearly 3,000 feet of rocks in the series, above the Millstone-grit, and 60 to 120 feet of coal.

In the Nova Scotia Coal-measures, there is evidence in the fossils that the waters were to a large extent fresh or brackish. The occurrence of a *Spirorbis* along with the *Pupa* and Reptilian remains, in the *Sigillaria* stump, has been considered as evidence, in this particular case, of the presence of brackish water during the burial of the stump. Only one bed in the Nova Scotia Coal-formation, above the Subcarboniferous portion, is known to contain marine fossils. The land-snail (*Pupa*) occurs also in a bed — an under-clay — over 1,200 feet below the level of the stump in which it was first found; and in this interval there are twenty-one coal-seams, showing, as Dawson observes, that the species existed during the growth and burial of at least twenty forests.

In the Interior Continental region, the submergence attending the formation of these intervening rocks was mostly or wholly marine; for all the fossils thus far observed are those of marine species; and they occur in many strata of limestone, sandstone, and shale, throughout the Coal-measures. In Central Pennsylvania, the evidences of marine life are uncertain. Over the great Mammoth bed of Wilkesbarre, are shales (in the township of Hanover) containing bivalve shells; but these may be of the fresh-water type of *Unionidæ*. The thinner shales, among the coal-beds of the Interior basin, and the limited arenaceous layers may have been formed when the marshes became flooded with fresh waters; while the great sandstones and limestones and thicker shales are all evidence that the former fresh-water marsh was followed, through submergence, by a flood of marine waters. The extermination of the Lepidodendrids of the Lower Coal-measures was probably connected with such a submergence. The marine waters probably came in from the Interior basin to the southwest, and not from the ocean on the east.

The Lower Coal-measures extend to the most eastern limits of the anthracite in Pennsylvania, and contain but little limestone, either in the east or west. The Upper, above the Pittsburg bed, extend only over the western portion of that State. This more western limit of the Upper than the Lower section shows plainly that a rising of the country had taken place more to the east, to a height that was too dry for the marsh-vegetation of which coal was made. We observe further, that limestones occur in the Upper Coal-measures, and increase much on going westward over the Interior basin; and, finally, as has been stated, they prevail extensively over the larger part of the Rocky Mountain region.

The coal-bed itself bears evidences of alternations of condition, in its own lamination, or even in the alternations in its shades of color. A layer an eighth of an inch thick corresponds to an inch, at least, of the accumulating vegetable remains; and hence the regularity and delicacy of the structure are not surprising. Alternations are a consequence of (1) the periodicity in the growth of plants and the shedding of leaves; (2) the periodicity of the seasons, the alternations of the season of floods with the season of low waters, or comparative dryness; (3) the occurrence, at intervals of several years, of excessive floods. Floods may bring in more or less detritus, besides influencing the fall and distribution of the vegetation. In some conditions, there would be a long steeping of the vegetation in the waters, before it was put under the pressure of beds of clay or sand; and the precise quality of the coal would be varied thereby, the decomposition of the vegetation depending on the amount of water, the composition of that water, and the length of time exposed. Newberry has suggested that bituminous coal has taken the form of Cannel when the vegetation was reduced to a perfect pulp at the time of the change to coal.

The Coal period was a time of unceasing change, — eras of universal verdure alternating with others of wide-spread waters, destructive of all the vegetation and other terrestrial life, except that which

covered regions beyond the Coal-measure limits. But yet it was an era in which the changes for the most part went forward with so extreme slowness, and with such prevailing quiet, that, if man had been living then, he would not have suspected their progress, unless he had records of some thousands of years past to consult. According to the reading of the records, it was a time of great forests and jungles, and of magnificent foliage, but of few or inconspicuous flowers; of Acrogens and Gymnosperms, with no Angiosperms; of marsh-loving Insects, Myriapods, and Scorpions, as well as Crustaceans and Worms, representatives of all the classes of Articulates, but not the higher Insects, that live among flowers; of the last of the Trilobites, and the passing climax of the Brachiopods and Crinoids; of Ganoids and Sharks, but no Teliosts or Osseous Fishes, the kinds that make up the greater part of modern tribes; of Amphibians and some inferior species of True Reptiles, but no Birds or Mammals; and therefore there was no music in the groves, save that of Insect life and the croaking Batrachian. Thus far had the world progressed, by the close of the Carboniferous period.

The special history of the Coal-period of Europe and Britain might be followed out, as has been done for North America. But the details would illustrate no new principles, and would be more appropriate in a general treatise than in a text-book. More facts are to be ascertained, before their history will be as clearly deciphered.

4. Formation of Mineral Coal. — From the analyses on page 316, it is seen (1) that mineral coal consists chiefly of *carbon;* (2) that, also, hydrogen and oxygen are always present; (3) that *Anthracite* contains usually 2 to 5 per cent. of oxygen and hydrogen; and the *Bituminous* coals often 12 per cent. in weight of oxygen, and 4 to 6 of hydrogen; while *Brown Coal*, the bituminous coal of later formations (which ordinarily gives a brownish-black powder), contains 20 per cent. or more of oxygen, with 5 or 6 of hydrogen.

Mineral coal, therefore, is not carbon, but a compound, or a mixture of two or more compounds, of carbon, hydrogen, and oxygen, associated probably with some free carbon in anthracite, and possibly in some or all bituminous coal. In this view, coals are mainly *oxydized hydrocarbons*, or mixtures of them. As stated on page 314, they are scarcely acted on by ether or benzine, and hence contain no mineral oil, or only a trace of any soluble hydrocarbon; but, at a high temperature, hydrocarbons (compounds of hydrogen and carbon) are given out, in the forms of either mineral oil, tar, or gas.

The coal, as has been shown, is derived from the alteration of vegetable material. This vegetable material is (*a*) woody fibre; (*b*) cellular tissue; (*c*) bark; (*d*) spores of Lycopods (Lepidodendrids, etc.);

(*e*) resins and associated substances. The following is the composition of (1) dried wood in the mass; (2) cork (the bark of *Quercus suber*); (3) the spores of Lycopods; (4, 5, 6) the common kinds of mineral coal; and (7) peat or vegetable material, partly altered to the coal-like condition.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.
I. *Woody Ingredients.*				
1. Wood	49·66	6·21	43·03	1·10
2. Cork	65·73	8·33	24·44	1·50 = 100
3. Lycopod Spores	64·80	8·73	20·29	6·18 = 100
II. *Coal Products.*				
4. Anthracite	95·0	2·5	2·5	
5. Bituminous Coal	81·2	5·5	12·5	0·8
6. Brown Coal	68·7	5·5	25·0	0·8
7. Peat	59·5	5·5	33·0	2·0

From this table, it appears that, in the change of woody fibre to *anthracite*, the diminution in the amount of oxygen and hydrogen is about ninety per cent., and that of the oxygen above ninety-five per cent.; in that to *bituminous coal*, the percentage of hydrogen is not very much altered, but that of the oxygen is reduced over seventy per cent.; in that to *brown coal*, the percentage of the hydrogen is the same nearly as in bituminous, but that of the oxygen is reduced only forty to forty-five per cent.

The relations of these woody materials and coals are still better exhibited in the following table, giving the atomic proportions of the constituents, carbon being made one hundred; the atomic equivalents of carbon, hydrogen, and oxygen being respectively 12, 1, 16.

	Carbon.	Hydrogen.	Oxygen.
1. Wood	100	150	65
2. Cork	100	150	30
3. Lycopod Spores	100	166	24
4. Anthracite	100	33	2
5. Bituminous Coal	100	83	12
6. Brown Coal	100	96	27
7. Peat	100	112.5	40

There was little ordinary bark in the beds of vegetable debris, since the cortical part of Lycopods, Ferns, and Calamites is not of this nature: although nearer coal in constitution than true wood, bark resists alteration longer, and is less easily converted into coal. The spores of Lycopods often retain their amber-yellow color in the coal, although undoubtedly changed in constitution. Resins, which are still nearer coal in the amount of carbon, but hold less oxygen, are found mostly as resins in coal, especially when they are in lumps or grains, but of somewhat altered composition.

The composition given above for dried wood is the mean of many analyses, by Petersen and Schödler (Liebig's Annalen, xvii. 141), as deduced by Bischof, corrected by

deducting 1·10 from the oxygen and making it nitrogen. Pure woody fibre and cellular tissue (cellulose) consist of Carbon 44·44, hydrogen 6·17, oxygen 49·39 = 100; but, through the presence of resinous and other matters, the average composition of wood is as stated. The mean composition for the wood of three common species of Pines (*Pinus larix*, *P. abies*, and *P. picea*) differs little from the average, it being (the nitrogen included with the oxygen) Carbon 49·84, hydrogen 6·37, oxygen 43·75 = 100. From Chevandier's various analyses (Ann. Ch. Phys., III. x. 129), the average constitution of wood is, Carbon 51·21, hydrogen 0·21, oxygen 41·45, nitrogen 1·10 = 100. His result differs from the preceding, mainly in the separation of the nitrogen from the oxygen.

The ultimate analysis of Cork, on the preceding page, is by Mitscherlich. Cork (one of the purest of barks) includes about ten per cent. of substances soluble in absolute alcohol, one of which contains over eighty per cent. of carbon, with little oxygen, and hence the low percentage of oxygen in the analysis of cork above cited. Bark also contains, on an average, twelve per cent. of tannic acid (a compound of Carbon 52·4 per cent., hydrogen 3·6, oxygen 44·0); and the rest of it is supposed to be impure cellulose.

Dawson has suggested, in view of the many Sigillaria stumps hollowed out by decay, and flattened stems of other trees, filled with shale or sandstone, found in the Coal-measures, that the vegetable debris from which the coal has proceeded was largely bark, or material of that general nature. But the occurrence of such stumps and stems outside of the coal-beds, while proof that the interior wood of the plants was loose in texture and very easily decayed, is no evidence that these trees contributed only their cortical portions to the beds of vegetable debris. Moreover, the cortical part of Lepidodendrids (under which group the Sigillarids are included by the best authorities) and of Ferns also, is made of the bases of the fallen leaves, and is not like ordinary bark in constitution; and Equiseta have nothing that even looks like bark. This cortical part was the firmest part of the wood; and for this reason it could continue to stand, after the interior had decayed away, — an event hardly possible in the case of a bark-covered Conifer, however decomposable the wood might be. Further, trunks of Conifers are often found in the later geological formations, changed, *throughout* the interior, completely to Brown coal or Lignite.

Lycopods and Equiseta have, like Ferns and Mosses, the same constitution with ordinary wood. The following are the results of analyses of species of these plants by Mr. George W. Hawes, and also of a *Sphagnum* (Peat-swamp moss) by Websky, the ash excluded: —

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	
1. Lycopodium dendroideum .	48·70	6·61	43·25	1·44	Hawes.
2. Lycopodium complanatum .	48·43	6·61	43·02	1·94	Hawes.
3. Equisetum hyemale . .	47·50	6·68	44·49	1·27	Hawes.
4. Sphagnum	49·88	6·54	42·42	1·16 = 100	Websky.

As the *Sphagnum* is made of cellular tissue, the analyses show that, in Lycopods, the cellular and vascular portions are essentially alike in constitution.

The fact that the spores of Lycopods retain an amber-like color, in the coal, proves that they do not yield to change so easily or thoroughly as the ordinary woody tissues, but approximate in this respect to particles of resin.

In the decomposition of wood and leaves in the air, the carbon and hydrogen combine with oxygen, — both external oxygen and that of the plant, — and the ultimate products are, as in the combustion of wood, carbonic acid (CO^2) and water (H^2O), with nothing left behind. Thus it is, essentially, with the leaves and stems that fall to the ground over the drier portions of the continent.

When the vegetable material is under water, the atmospheric oxygen is excluded, except the small part contained in water; and this oxygen, with some proceeding from the growing plants in the waters,

is all that comes from external sources. Under this diminished supply, part of the carbon and hydrogen escape oxydation, and a coaly product is left behind. This covering of water prevents a complete combustion of the material, just like the covering of earth over burning wood, when charcoal is made. The air might also be partly or wholly excluded from vegetable debris, by a covering of clay or earth; and this is generally what happened, sooner or later, in the Carboniferous period.

The changes attending the ultimate decomposition under these circumstances depend on the affinity of (1) the carbon for oxygen, making carbonic acid; (2) of hydrogen for oxygen, producing water; (3) of carbon for hydrogen, making carbo-hydrogen gas or oil; and (4) on the tendency of the carbon and hydrogen, under certain proportions, to form, with a portion of the oxygen, the stable compounds included under the term *Coal.* The carbonic acid and water escape, and also the carbo-hydrogen gas; and, consequently, under the most favorable circumstances, the wood loses, in the change, much carbon and hydrogen as well as oxygen. It is probable that, in the making of bituminous coal, at least three-fifths of the material of the wood are lost; and, in the making of anthracite, three-fourths. Besides this reduction to two-fifths and one-fourth by decomposition, there is a reduction in bulk by compression; which, if only to one-half, would make the whole reduction of bulk to one-fifth and one-eighth. On this estimate, it would take five feet in depth of compact vegetable debris to make one foot of bituminous coal, and eight feet to make one of anthracite. For a bed of pure anthracite thirty feet thick, (like that at Wilkesbarre), the bed of vegetation should have been at least 240 feet thick.

Anthracite coal is a result, as remarked upon beyond, of the action of heat on bituminous coal, under pressure, attending an upturning of the rocks, the heat driving off nearly all volatile matters it could develop, and so leaving a coke (the anthracite) behind. Made in this way, the reduction, in the case of anthracite, would be to about one eighth, as above estimated. The average amount of ash in anthracite ought, consequently, to be nearly half greater than in bituminous coal.

If the vegetable debris were so buried that no external oxygen were concerned in the change attending the decomposition, and if all the oxygen of the wood went to form carbonic acid with part of the carbon, the result would be a kind of mineral oil; for dry wood has approximately the composition $C^6H^9O^4$; removing from twice this, $C^{12}H^{18}O^8$, $4CO^2$ (which would take off all the oxygen), there would be left C^8H^{18}, the composition of a species of the naphtha group. So also, animal oils, on the simple separation of carbonic acid, may become mineral oils. Warren & Storer obtained, by the destructive distillation of the oil of the white-fish, after its saponification by lime, the various oils of the marsh-gas group, besides others of the ethylene and benzole series. It is well known, also, that similar oils are obtained by the destructive distillation of wood.

But the change could not be as simple as here indicated, since (1) there is some nitrogen present in plants; (2) the plants would have undergone some change before the complete burial; (3) some water and carbo-hydrogen might also be made and escape, though it is not probable that the amount would be large. The facts still illustrate a possible mode of transformation. But since part of the oxygen remains in all coals, only part of the oxygen of the wood has gone to produce carbonic acid; and, moreover, external oxygen has taken some part in making this gas, or the water that is given off. The amount of oxygen present is much the largest in *Brown coal*, and probably because external oxygen was more concerned in the transformation than in the making of Carboniferous bituminous coal.

Bischof has calculated that, if the escaping product is carbonic acid and water, derived from the elements of the wood (which might be the case if external oxygen were completely excluded), the amount of coal left, in the case of bituminous coal, would be about 54 per cent. If the escaping gases were carbonic acid and hydrogen, the latter combining with external oxygen to form water, the amount of bituminous coal left would be about 42 per cent.

It is also to be noted, that, in the derivation of coal from vegetable matters, there may be, as suggested by S. W. Johnson, a process carried forward of molecular condensation, such as organic chemistry affords many examples of, which may account for the increased density of the product, and for the occurrence of the maximum density in anthracite.

In the formation of peat, — the first step toward Brown coal, — both carbonic acid and water escape, with also a little carbo-hydrogen gas (marsh-gas) and nitrogen; and the peat, which results, is chiefly, according to late experiments, humic acid. Brown coal also contains probably some humic acid, as is indicated by the brown color it gives to a solution of potash when heated with it. No such color is obtained with bituminous coal or anthracite.

The gas bubbling up from a marsh afforded Websky: Carbonic acid (CO^2) 2·97, marsh-gas (CH^4) 43·36, nitrogen 53·67 = 100. The carbonic acid is proportionally small; because it is soluble in water, and also because it may enter into combination with earthy ingredients present in the ash. The amount of escaping nitrogen shows that coal retains but little of that in the vegetable and animal life of the marsh.

See, further, on the making of Coal and Peat, Bischof's "Chemical Geology" Websky, in the Jour. f. pr. Chem., xcii.; Hunt, in Am. Jour. Sci., II. xxxv., and the Canadian Naturalist, vi. 241; S. W. Johnson, on "Peat and its Uses."

Impurities of the Coal. — The impurities of the coal are in part derived from the wood.

1. *Silica* is present in the exterior part of the stems of Equiseta (the representatives of the ancient Calamites), to such an extent that the plants sometimes afford 25 per cent. of ash, with half this silica, that is, 100 lbs. of the dried plants contain 12½ lbs. of silica; and it exists in smaller proportions in the interior of all plants.

2. *Alumina*, while absent from most plants, constitutes 22 to 50 per cent. of the ash of some modern species of Lycopods.

3. *Lime* and *Magnesia* are present in small proportions in the ash of all plants. In *Charæ*, species that existed in the Carboniferous era, and which afford 30 per cent., or more, of ash, 95 per cent. are carbonate of lime.

4. *Oxyd of iron* is present in many plants. The ash of one *Lycopod* afforded 6 per cent. of this oxyd; and the same is true of a *Sphagnum*.

5. *Potash* is present in all terrestrial vegetation, and *soda* more sparingly; but, as the salts of these alkalies are soluble, they would mainly disappear in the course of the decomposition.

6. Traces of *sulphur* occur in wood, as well as in animal matters, which therefore would be present in the accumulating beds. This *sulphur*, by combination with iron, would have formed *pyrite*, — a common impurity in coal-beds. But it seems also to exist in coal in a resin or some other organic compound. *Nitrogen* is present in coals, but under what condition is not known.

Impurities were also introduced, as earth or clay, by waters, as the occasional intercalations of shale show. Even the winds transport dust, and may have contributed to the earthy ingredients of the coal.

Waters may also have carried in other ingredients *in solution*, as oxyd of iron, in combination with either carbonic acid, sulphuric acid, or some organic acid; for iron is carried in these ways (mainly the last) into all marshy or low regions, from the hills around, being derived from the decomposition of iron-bearing minerals. Sulphate of iron would lose its oxygen from contact with decomposing vegetation, and become sulphid of iron; and this is another source of pyrite. In the change, the oxygen takes carbon from the coal or decomposing plants, and forms carbonic acid, which escapes, and leaves only sulphur and iron, to make sulphid of iron, or pyrite. The carbonic acid made in the change of wood to coal was in part utilized by its combination with iron in the protoxyd state, making carbonate of iron, the ordinary constituent of the iron ore of coal regions. Sesquioxyd of iron, in contact with decomposing vegetation, becomes protoxyd, which then unites with the escaping carbonic acid.

The following are analyses of the ash of *Lycopods* (1, 2), *Ferns* (3 to 6), *Equiseta* (7, 8), *Conifer* (9), Moss of the genus *Sphagnum* (10), and *Chara* (11).

	KO	NaO	CaO	MgO	Fe^2O^3	Mn^3O^4	Al^2O^3	PO^5	SO^3	SiO^2	Cl
1. Lyc. clavatum .	31·90	2·68	4·13	5·89	6·00	–	22·20	7·30	3·55	13·01	–
2. Lyc. clavatum .	25·69	1·74	7·96	6·51	2·30	2·53	26·65	5·36	4·90	13·94	3·13
3. Aspl. filix . .	45·5	5·2	7·9	7·4	1·5	–	–	20·0	6·8	2·2	4·6
4. Aspid. filix . .	39·80	5·31	18.74	8·28	0·97	–	–	2·56	5·40	4·38	14·72
5. Osm. spicant .	23·65	3·33	4·09	6·47	1·17	–	–	1·76	1·29	53·00	5·82
6. Pteris aquilina .	19·35	4·78	12·55	2·30	3·94	–	–	5·15	1·77	43·65	6·20
7. Eq. arvense . .	19·16	0·48	17·20	2·84	0·72	–	–	2·79	10·18	41·73	6·26
8 Eq. Telmateia .	8·01	0·63	8·63	1·81	1·42	–	–	1·37	2·83	70·64	5·59
9. Pinus abies . .	12·84	5·64	58·27	2·81	1·60	*tr.*	*tr.*	2·60	1·60	12·55	2·06
10 Sphag. commune	8·02	12·40	3·17	4·92	6·35	*tr.*	5·89	1·06	4·33	41·69	12·09
11. Chara fœtida .	0·85	0·44	95·35	0·99	0·67	–	–	0.54	0·42	1·22	0·16

Analysis 1, is by Ritthausen; 2, Aderholt; 3, A. Weinhold; 4, Struckmann; 5, 6, 9, Malaguti & Durocher; 7, 8, E. Wittig; 10, H. Vohl.; 11, Schulz-Fleet.

In the analyses that have been made of Lycopods, the amount of ash is 3·2 to 6 per cent. in weight of the dried plant; of Ferns, 2·75 to 7·56 per cent.: of *Equisetum arvense*, 18·71 per cent.; of *Eq. Telmateia*, 26·75 per cent.; of Conifers, mostly less than 2 per cent.; of *Chara fœtida*, 31·33 per cent.; of *Fungi*, 3·10 to 9·5 per cent.; of Lichens,

1·14 to 17 per cent. (the last in *Cladonia*), but mostly between 1·14 and 4·30 per cent. In *Lycopodium dendroideum*, Hawes, in his analyses (p. 362), found 3·25 per cent. of ash; in *L. complanatum*, 5·47 per cent., and in *Equisetum hyemale*, 11·82 per cent.

Lycopodium chamæcyparissus afforded Aderholt 51·85 per cent. of alumina; or, when without spores, 57·36 per cent.; while Ritthausen obtained 39·07 alumina for this species, and 37·87 for *L. complanatum*. In Lycopods, the silica constitutes 10 to 14 per cent. of the ash. In the ash of Mosses have been found 8 to 23·58 per cent. of potash, 4 to 16 of silica, 1·06 to 6·56 of phosphoric acid, 4·9 to 10·7 of magnesia. Among Ferns, the amount of ash, so far as determined, varies from 5 to 8 per cent.

The ash of *Fungi* affords 21 to 54 per cent. of potash, 0·36 to 11·8 of soda, 1·27 to 8 of magnesia, 15 to 60 of phosphoric acid, and 0 to 15·4 of silica. Among Lichens, the ash of *Cladonia rangiferina* contains 70·34 per cent. of silica; of other species, less, down to 0·9 per cent.

Trapa natans, of bogs, in Europe, affords 13 to 25 per cent. of ash; and 25 per cent. of this are oxyd of iron (Fe^2O^3) with a little oxyd of manganese. Of the ash of the fruit scales, over 60 per cent. are oxyd of iron.

Since, according to the average composition of Lycopods, the dried plant affords 5 pounds of ash to 100 of the plant, and 40 per cent. of this is alumina and silica (27 alumina and 13 silica), these two ingredients make up 2 per cent. of the plants. Ferns, with the same amount of ash, afford, as the average, 27 per cent. of silica, with no alumina. *Equiseta* afford, on an average, 20 per cent of ash, and 50 per cent. of this may be silica. Supposing, now, that Lycopods (*Lepidodendrids*, etc.) afforded one half the material of the coal-beds, and the other plants the rest, and that the silica and alumina of the former averaged 40 per cent., and of the latter only 27 per cent., this being all silica, then the amount of these ingredients afforded by the vegetation would be 1·66 per cent. of the whole weight when dried. This would make the amount of silica and alumina, in the bituminous coal made from such plants (supposing three fifths of the material of the wood lost in making the coal, as estimated on page 363), 4 per cent.; and the whole amount of ash about 4·75 per cent. At the same time, the ratio of silica to alumina would be nearly 3 to 2.

Now many analyses of the bituminous coal of the Interior basin have obtained not over 3 per cent. of ash, or impurity, although the general average, excluding obviously impure kinds, reaches 4·5 to 6 per cent.; being, for the coals of the northern half of Ohio, 5·12, and for the southern half 4.72.

It hence follows that (1) the whole of the impurity in the best coals may have been derived from the plants; (2) the amount of ash in the plants was less than the average in modern species of the same tribes; (3) the winds and waters for long periods contributed almost no dust or detritus to the marshes; and (4) the ash, or else the detritus, was greatest in amount toward the borders of the Interior marsh-region. In that era of moist climate and universal forests, there was almost no chance for the winds to gather dust or sand for transportation.

3. PERMIAN PERIOD (15).

The Permian period, the closing era of the Carboniferous age, was a time of decline for Paleozoic life, and of transition toward a new phase in geological history.

The term *Permian* was given by Murchison, De Verneuil, and Keyserling, after the ancient kingdom of Permia, in Russia, which included the existing governments of Perm, Viatka, Kazan, Orenburg, etc., where the formation exists. In America, no division of the Permian period into epochs has been recognized.

1. American.

I. Rocks: kinds and distribution.

An upper portion of the Carboniferous formation in Pennsylvania and Virginia has been shown by the plants to be Permian (Fontaine and White), and in Illinois and Texas, by the Reptiles and Amphibians (Cope). Permian rocks occur in Kansas, and some parts of the Rocky Mountain region, overlying conformably the Carboniferous, and making one continuous series.

The rocks are limestones, sandstones, red, greenish, and gray marlytes or shales, gypsum beds, and conglomerates, among which the limestones in some regions predominate.

In Kansas, they outcrop along the western border of the Carboniferous region, and also in patches to the east of this range. On the map, p. 144, the Permian is distinguished by light dots on a dark ground. The beds occur also about the Black Hills (near lat. 44° N. and long. 104° W.), on the eastern slope of the Big Horn Mountains, and, according to Shumard, in the Guadalupe Mountains in New Mexico.

The whole thickness made out by Swallow & Hawn is about 820 feet; and 263 feet of this are called by them the *Upper* Permian, and the rest the *Lower*. Meek & Hayden refer the Lower division, with good reason, and also a part of the Upper, to the Upper Coal-measures. The limestones are usually impure, and also magnesian, like most of the limestones of the same region of older date. They are generally rather soft or irregular in structure, and much interlaminated with clayey or arenaceous beds. Some of the layers contain hornstone. In a review of the Nebraska Carboniferous fossils, Meek refers all to the Upper Coal-measures, although they contain a few genera and species that are especially characteristic of the European Permian. (Hayden's Rep. on Nebraska, 1872.)

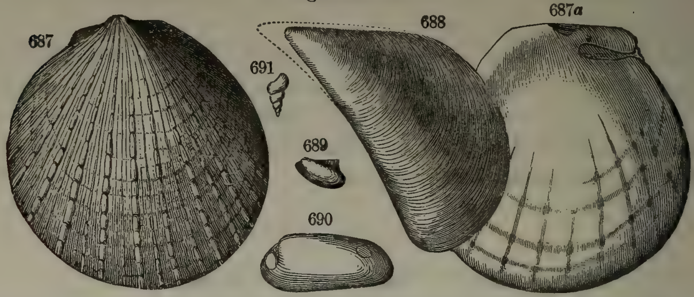
II. Life.

Some of the peculiarly Permian plants of West Virginia are species of Callipteris (*C. conferta*), Alethopteris (*A. gigas*), Odontopteris (*O. obtusiloba*), several arborescent Pecopterids, and Conifers of the genus Saportæa.

The species from Kansas here figured occur in the uppermost beds (Meek & Hayden). Fig. 687, *Pseudomonotis Hawnii* M. & H., cast of the outside of the left valve; 687 *a*, cast of the interior of the right valve of the same. The genus *Pseudomonotis*

is related to *Avicula:* it has an opening below the beak, for the passage of the byssus, as shown in the figure. Fig. 688, *Myalina perattenuata* M. & H.; Fig. 689, *Bakewellia parva* M. & H.: Fig. 690, *Pleurophorus subcuneatus* M. & H.; Fig. 691, shell of a small undetermined *Gasteropod.* On Permian Reptiles, see page 851.

Figs. 687–691.



Mollusks.—Figs. 687, 687 *a*, Pseudomonotis Hawnii; 688, Myalina perrattenuata; 689, Bakewellia parva; 690, Pleurophorus subcuneatus; 691, an undetermined Gasteropod.

Among the species of Mollusks from the beds referred to the Permian by Swallow, 75 in number, nine tenths occur also in the Carboniferous beds below.

III. General Observations.

We observe the following facts connected with the period: (1.) The beds are apparently all marine strata, for the fossils are marine. (2.) The numerous alternations, between impure limestones and clays and some sand deposits, indicate oscillations through the period in the depth of water, between moderate depths and very shallow waters. (3.) The absence of coal beds is proof that there were no fresh-water Carboniferous marshes in the regions where the rocks have thus far been examined. (4.) The occurrence of these marine strata over the region *east* of the Mississippi seems to show that this eastern part of the continent was still undergoing oscillations. Early in the Carboniferous period, eastern Pennsylvania may have been raised, and made dry land; for only the *Lower* Coal-measures occur there; but this was, apparently, not true of the southwestern part of the State or of West Virginia. (5.) The *western* beds occur within the same region, or on the borders of the same region, in which the Coal-formation during the Carboniferous period was represented by limestones; that is, in the great interior sea which had so long existed as the Paleozoic representative of the Gulf of Mexico,—a comparatively shallow, but extensive, inland sea, stretching northward. The present western limit of the Gulf is nearly in a north-and-south line with the western boundary of the State of Kansas. The existence of the Permian deposits was owing to a continuation of the conditions that characterized the Carboniferous period. That

era, limestone-making over these western regions, was prolonged into another, when the limestones formed still, but with numerous interruptions by clay-depositions. The beds are continuous with the Carboniferous, without interruption or unconformability, and yet are referred to the *Permian*, because they probably belong to the Permian period in geological time, or, at least, its earlier portion.

2. Foreign Permian.

I. Rocks: kinds and distribution.

The Permian strata of England outcrop along the borders of the several coal regions, excepting that of South Wales. They occupy a small area in Ireland, about the Lough of Belfast. They consist of *red sandstone and marlytes*, along with *magnesian limestone*. In Europe, the Permian beds in like manner border directly upon the Coal-measures; and to a large extent the fossil plants are of Coal-measure species.

The Permian beds, before their relations were correctly made out, were included, along with part of the Triassic, under the name "New Red Sandstone."

They occur, over small areas, in central Germany, from southern Saxony along the Erz Mountains, over the adjoining small German States, west to Hesse Cassel, and north to the Hartz Mountains and Hanover. Within this area, Mansfeld is one noted locality, situated in Prussian Saxony, not far from Eisleben; another is on the southwest borders of the Thuringian forest (Thüringerwald), in Saxe-Gotha, a line which is continued on to the northwest, by Eisenach, toward Münden in southern Germany.

In Thuringia and Saxony, the subdivisions of the rocks, beginning below, are (1) the *Rothliegende* or Red beds (called also *Todtliegende*), consisting of red sandstone, and barren of copper ores; near the town of Eisenach, about 4,000 feet thick. (2.) The *Zechstein formation*, or magnesian limestone, consisting of (*a*) the *Lower Zechstein*, a gray, earthy limestone, overlying the *Kupferschiefer*, or copper-bearing shales, and the still lower *Weissliegende* or *Grauliegende*, or white or gray beds; (*b*) the *Middle Zechstein*, magnesian limestone, called the *Rauch-wacke* and *Rauhkalk;* (*c*) the *Upper Zechstein*, or the *Plattendolomit*, and including the impure fetid limestone called *Stinkstein.* The formation to the southward loses its limestone. The whole Permian has been called, in Germany, the *Dyas*, from the Greek for *two*, in allusion to the two principal strata of which it there consists. (For an account of it, see Murchison's "Siluria," and also, especially for its fossils, Geinitz's "Dyas," in 4to, Leipzig, 1861, 1862.)

In Durham, England, there is (1) a Lower Red Sandstone, 200 feet thick (corresponding to the Rothliegende of Germany); then (2), *a*, 60 feet of marl-slate (corresponding to the Kupferschiefer); *b*, two strata of magnesian limestone, the lower 500, and the upper 100 feet thick, separated by 200 feet of gypseous marlyte, and overlaid by 100 feet of the same. The magnesian and other limestones disappear to the south, near Nottingham. In Northwestern England, the Lower Permian includes 3,000 feet of marlytes and sandstones; the Middle, only 10 to 30 feet of magnesian limestone; the Upper, 600 feet, similar to the Lower. The red sandstones of Rhone Hill, near Dungannon, Tyrone, Ireland, are supposed to be Permian. There are detached Permian areas in Dumfriesshire, Ayrshire, etc., in Scotland. In Ayrshire, they cover the Coal-measures, and have some beds of igneous rock at base.

In Russia, the two German divisions are recognized, (1) magnesian limestones interlaminated with sandstones of true marine origin, (2) overlying marlytes of various

colors, of marsh origin, with some gypsum. There is an occasional thin seam of coal. The strata cover a region over the interior of Russia more than twice as large as all France, including the greater part of the governments of Perm, Orenburg, Kazan, Nijni Novgorod, Yaroslavl, Kostroma, Viatka, and Vologda (Murchison). The deposits are flanked and underlaid on nearly all sides by different members of the Carboniferous formation containing comparatively little coal.

The coincidence is worth noting, that the Permian rocks of Russia, or interior Europe, lie between its great river, the Volga, and the summit of the Ural Mountains, just as, in interior North America, they occur between its great river, the Mississippi, and the Rocky Mountain summits. It may be that, on both continents, the region between the great river and the ocean had been raised above the sea during the preceding changes.

The Permian has also been recognized near Bell Sound in Spitzbergen; and Von Köninck has described several fossils from it.

The coal formation of Illawarra and Hunter's River, Australia, is probably Permian, as stated by the author in his notes on Australian Geology, Geol. Rep. Wilkes' Expl. Exped., 4to, 1849.

The lower part of the Lower Permian of England contains, in some places, beds of coarse conglomerate, containing angular masses of rock of great size; and Ramsay attributes the transportation of the blocks to *floating ice.*

II. Life.

1. *Plants.*

The Permian plants are closely related to those of the Upper Coal-measures. They are mostly of the same genera, and in part of the same species. There are *Calamites, Equiseta, Ferns,* including Tree-

Figs. 692–695.

Figs. 692, 693, Neuropteris Loschii; 694, 694 *a*, Annularia carinata; 695, Walchia piniformis.

ferns, and a number of *Conifers* and *Cycads;* yet the prevalence of some new kinds gives a somewhat different aspect to the flora. Among Lycopods, the genus *Walchia* (Fig. 695) is most characteristic.

The Ferns were of the genera *Neuropteris, Sphenopteris, Pecopteris, Alethopteris,* etc.; and there were also species of *Asterophyllites* and *Annularia,* as well as *Calamites,* Coal-measure genera. *Calamites gigas* Brngt. is a large and common species. On the other

hand, there were few *Sigillarids*. The Conifers were more varied: they included species of *Dadoxylon*, *Pinites*, *Ullmannia*, etc. The genus *Walchia*, characterized by lax and very short spreading leaves, began near the close of the Carboniferous period, but is much more numerous in species during the Permian. It has been considered a Conifer; but the fruit, according to Geinitz, is that of a Lycopod. Tree-ferns of the genus *Psaronius* were common, as in the Upper Coal-measures. Fruits are described, by Geinitz, of the genus *Gulielmites*, which he supposes to be of the Palm tribe.

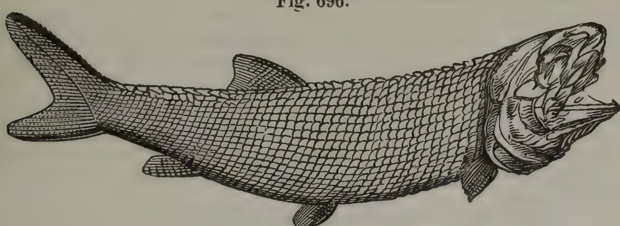
Fig. 692, pinnule or branchlet of a large frond of *Neuropteris Loschii*, a species common to the Permian and Coal-measures, as well also as *Pecopteris arborescens*, *P. similis*, and some other plants; 693, a portion showing the venation. Fig. 694, a small part of a specimen of *Annularia carinata* Sternberg; the stem is jointed, as in the Equiseta, and gives off branchlets at the articulations; these branchlets are also jointed, and have whorls of leaf-like appendages at the articulations. In 694, only the first joint and its whorl are shown, of natural size; in 694 *a*, a branch is shown (of reduced size), consisting of its several joints and whorls, but the natural termination is wanting. Fig. 695, *Walchia piniformis* Sternberg. The figures are from the work of Geinitz and Gutbier on the "Dyas" of Saxony.

2. *Animals.*

Corals of the *Cyathophyllum* family, Brachiopods of the genera *Productus*, *Spirifer*, and *Orthis*, Pteropods of the genus *Conularia*, Cephalopods of the genus *Orthoceras*, and Ganoid fishes with vertebrated tails, give a Paleozoic character to the Fauna. But there are many new features: among these, the most prominent is the appearance of Crocodilian Reptiles of the tribe of *Thecodonts* — species having the *teeth set in sockets*, as the name (from the Greek) implies.

This transition-character is apparent also in the number of old animal as well as vegetable types that here nearly or quite fade out, — for it is the period of the last of the species of *Productus*, *Orthis*, *Murchisonia;* nearly the last of the extensive tribe of *Cyathophylloid* corals, which made coral reefs of far greater extent than those of modern seas; nearly the last of the extreme vertebrate-tailed (heterocercal)

Fig. 696.



Palæoniscus Freieslebeni (×⅓).

Ganoid fishes. These groups had already dwindled much, before the Permian period; for some prominent Carboniferous genera, as the *Goniatites*, do not reach into it. The old or Paleozoic world was passing by, while within it new types had come forth, prophetic of the earth's brighter future.

Characteristic Species.

1. Radiates. — (*a.*) *Polyps.* — Cyathophylloid Corals. (*b.*) *Acalephs.* — Corals of the genus *Stenopora.* (*c.*) *Echinoderms.* — Crinoids near *Cyathocrinus;* Echinoids of the genus *Eocidaris,* near the Paleozoic *Archæocidaris.*

2. Mollusks. — (*a.*) *Bryozoans.* — *Fenestella retiformis* Vern., found in the Permian of Russia, England, and Germany, besides a dozen other related species.

(*b.*) *Brachiopods.* — *Spirifer alatus* Schloth., from England, Lower Zechstein in Saxony, — some specimens 2½ in. broad; *Spiriferina cristata* Dav., from the Zechstein, Germany; *Productus horridus* Sow., from England and Germany, characteristic particularly of the Lower Zechstein, and occurring also in the Kupferschiefer; *Strophalosia excavata* Gein., England, Germany; the species of the genera *Productus* and *Strophalosia* are exceedingly abundant in individuals; *Camarophoria Schlotheimi* Von Buch, from Russia, Germany, and England; the genus is related to *Terebratula* and *Pentamerus,* and is peculiar to the Carboniferous and Permian; *Camarophoria superstes,* Russia.

(*c.*) *Lamellibranchs.* — *Pseudomonotis speluncaria* Beyr., England, Russia, and Germany in the Lower Zechstein; *Clidophorus Pallasi* Gein., Russia and Germany; *Myalina squamosa* Sedg., Russia, England; *Avicula Kazanensis* Vern., Russia; *Bakewellia antiqua* King, England, Russia, Germany; *Schizodus dubius* M., a very common species in England, Germany, and Russia; *Schizodus Schlotheimii* Gein., *S. obscurus* Sow., and *S. truncatus* King. The genus *Schizodus* is of the same family with *Trigonia,* a characteristic genus in the Reptilian age: it commenced in the Devonian.

(*d.*) *Gasteropods* are rare fossils in the Permian. There are a few species of *Murchisonia* and *Straparollus,* Paleozoic genera, besides some others.

(*e.*) *Pteropods* of the genera *Theca* and *Conularia.*

(*f.*) *Cephalopods* existed, and among them two or three species of *Orthoceras.*

3. Articulates. — No *Trilobites* are known. *Ostracoids* are common. Under Tetradecapods, occurs here the *Amphipod, Prosoponiscus problematicus,* from the Permian of Durham, England, first described by Schlotheim, but recently explained by Bates. *Decapods* of the order of *Macrourans* appear to have commenced in the Coal formation. But the first of the *Brachyurans* is announced from the Permian by Von Schauroth, who names it *Hemitrochiscus paradoxus.* It is an eighth of an inch long. Geinitz regards it as related to the Pinnotheres family.

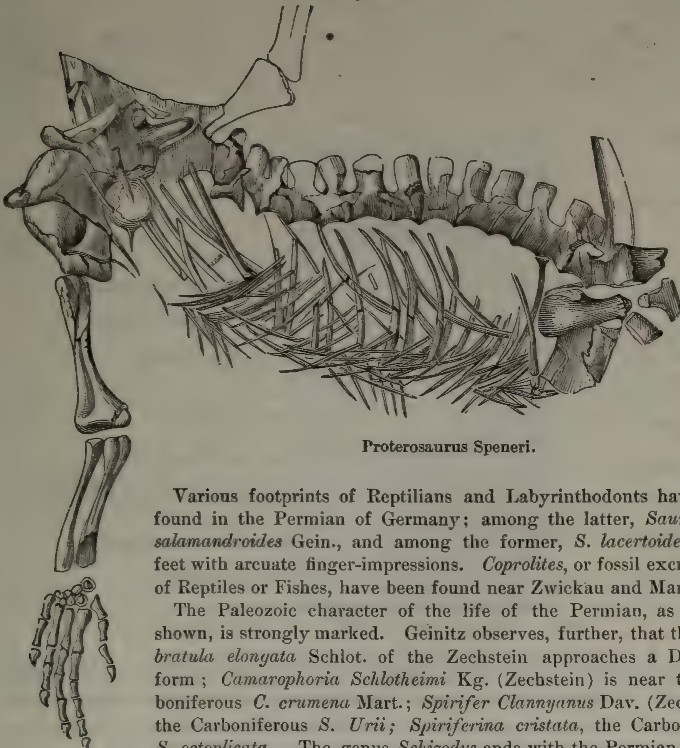
4. Vertebrates. — (*a.*) *Fishes.* — Fig 696, *Palæoniscus Freieslebeni* Agassiz, one-third the natural size; common in the Kupferschiefer, and also found in the Coal-measures in England, at Ardwick. Over forty species of fishes have been described. The more characteristic genera are *Palæoniscus, Platysomus, Acrolepis, Pygopterus,* and *Xenacanthus,* but they are also all Carboniferous. Besides the above, the species include *Palæoniscus elegans* Sedgw., *P. comptus* Ag., *Platysomus macrurus* Ag., *Pl. gibbosus* Bl., *Acrolepis Sedgwickii* Ag., *Pygopterus mandibularis* Ag., *Cœlacanthus granulatus* Ag., etc. *Janassa bituminosa* Münst. and *Wodnika striatula* Münst. are species of Cestraciont sharks from the Kupferschiefer. *Menaspis armata* Ewald, from the Kupferschiefer, has been regarded as a Cephalaspid related to *Pteraspis,* but also as the head or tail shield of a Crustacean.

(*b.*) *Amphibians, Reptiles.*—A number of Labyrinthodonts have been described, and also Reptiles of the tribes of Lacertians and Theriodonts. Fig. 697 represents one of the Permian Lizards, *Proterosaurus Speneri* Meyer; it was 3½ feet long, and is from the copper-slate (Kupferschiefer) of Germany and Saxony. Two other species have been found at Durham, England, along with Labyrinthodonts. *Dasyceps Bucklandi* Huxley is a Labyrinthodont, from Kenilworth, England, the specimen a cranium 10 inches long and 9¼ broad. See, further, the note on page 851.

These Permian Lizards had biconcave vertebræ, like the inferior swimming reptiles, but the socket teeth of the Crocodiles. The teeth were flattened, and crenulate at the

margins. The fingers in the *Proterosaurus* call to mind those of the Pterodactyl, as Geinitz suggests. The name *Proterosaurus* is from πρότερος, *first,* and σαῦρος, *lizard.*

Fig. 697.



Proterosaurus Speneri.

Various footprints of Reptilians and Labyrinthodonts have been found in the Permian of Germany; among the latter, *Saurichnites salamandroides* Gein., and among the former, *S. lacertoides* Gein., feet with arcuate finger-impressions. *Coprolites*, or fossil excrements, of Reptiles or Fishes, have been found near Zwickau and Mansfeld.

The Paleozoic character of the life of the Permian, as already shown, is strongly marked. Geinitz observes, further, that the *Terebratula elongata* Schlot. of the Zechstein approaches a Devonian form; *Camarophoria Schlotheimi* Kg. (Zechstein) is near the Carboniferous *C. crumena* Mart.; *Spirifer Clannyanus* Dav. (Zechstein), the Carboniferous *S. Urii; Spiriferina cristata*, the Carboniferous *S. octoplicata*. The genus *Schizodus* ends with the Permian, as well as *Orthis, Camarophoria, Productus*, and *Strophalosia*.

IV GENERAL OBSERVATIONS ON THE PALEOZOIC AGES.

I. Rocks.

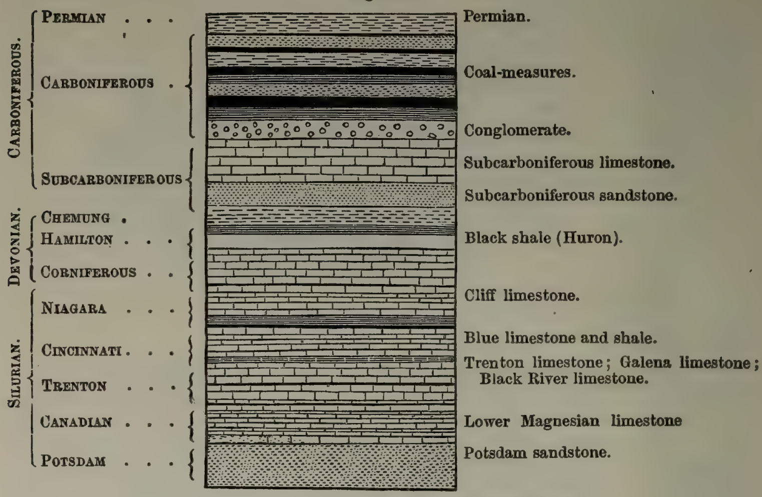
1. *Maximum thickness.* — The maximum thickness of the Silurian rocks of North America is at least 25,000 feet; of the Devonian, about 14,400 feet; and of the Carboniferous, nearly 16,000 feet.

2, *Diversities of the different Regions of the continent with regard to the kinds of rocks.* — The rocks of the *Appalachian region* are mainly fragmental, the limestones forming only a fourth of the whole thickness. The strata of the *Interior Continental basin* are mostly limestones, these constituting full two-thirds of the series. Although New York is situated mostly within the Interior basin, it still adjoins the Appalachian region, and partly lies within its border. Some idea

of the contrast between the two regions may be gathered from a comparison of the section of the New York rocks, on p. 142, with the general section of the formations in the Mississippi valley here presented.

In the Lower Silurian of this section, the Calciferous beds are mainly of limestone, as well as the Trenton and the greater part of

Fig. 698.



Section of the Paleozoic rocks in the Mississippi basin.

the Cincinnati Group. The Upper Silurian contains little but limestone; the Lower Devonian and the Subcarboniferous are also mainly limestone. Moreover, many limestone beds intervene in the Coal measures; and, west of the Mississippi, over a considerable portion of the Rocky Mountain slope, the Carboniferous beds are mainly limestones.

The rocks of the northern border of the Interior Continental basin, toward the Archæan, contain a much smaller proportion of limestone than those of the central portion.

The contrast between the Appalachian region and the Interior will become more apparent from a few general sections. The *first* here given is from the State of Pennsylvania, which lies within the Appalachian region; it is from the Geological Report of H. D. Rogers; the *second* is a section of the Ohio rocks, lying on the eastern border of the Interior basin, from the Geological Reports of J. S. Newberry; the *third* is a section of the Michigan rocks, lying on the northern side of the basin, by A. Winchell; the *fourth*, of Iowa, which is also on the northern side, by C. A. White; the *fifth* and *sixth*, of Illinois and Missouri, which are near its centre, — the former by A. H. Worthen, the latter by G. C. Swallow, but with changes from more recent information; the *seventh*, of Tennessee, of which the eastern part is in the Appalachian region, and the middle and western in the Interior, by J. M. Safford. In each case, the section begins below.

1. *Pennsylvania Section.*

Lower Silurian.

PRIMORDIAL, *Potsdam Epoch.* — "Primal Series" of Rogers, — sandstones and slates 3,000-4,000 feet.

CANADIAN, *Calciferous Epoch.* — "Auroral" calcareous sandstone, 250 feet.

Quebec and Chazy Epochs. — "Auroral" magnesian limestone, with some cherty beds, 5,400 feet.

TRENTON, *Trenton Epoch.* — "Matinal" limestone, with blue shale, 550 feet.

Utica Epoch. — "Matinal" bituminous shale, 400 feet.

Cincinnati Epoch. — "Matinal" blue shale and slate, with some thin gray calcareous sandstones, 1,200 feet.

Upper Silurian.

NIAGARA, *Oneida Epoch.* — "Levant Gray" sandstone and conglomerate, 700 feet.

Medina Epoch. — "Levant Red" sandstone and shale, 1,050 feet; and "Levant White" sandstone, with olive and green shales, 760 feet: total, 1,810 feet.

Clinton Epoch. — "Surgent Series," shales of various colors, both argillaceous and calcareous, with some limestones, ferruginous sandstones, and iron-ore beds, 2,600 feet.

Niagara Epoch. — Not well defined; possibly corresponds with part of the "Surgent" series.

SALINA, *Saliferous Epoch.* — "Scalent" variegated marls and shales, some layers of argillaceous limestone, 1,650 feet.

LOWER HELDERBERG. — "Scalent" limestone, thin-bedded, with much chert, 350 feet; "Pre-meridian" encrinal and coralline limestone, 250 feet; total, 600 feet.

ORISKANY, *Oriskany Epoch.* — "Meridian" calcareous shales, and calcareous and argillaceous sandstone, 520 feet.

Devonian.

CORNIFEROUS, *Cauda-galli Epoch.* — "Post-meridian" silico-calcareous shales, 200-300 feet.

Corniferous Epoch. — "Post-meridian" massive blue limestone, 80 feet.

HAMILTON, *Marcellus Epoch.* — "Cadent" Lower black and ash-colored slate, with some argillaceous limestone, 800 feet.

Hamilton Epoch. — "Cadent" argillaceous and calcareous shales and sandstone, 1,100 feet.

Genesee Epoch. — "Cadent" Upper black calcareous slate, 700 feet.

CHEMUNG, *Portage Epoch.* — "Vergent" dark-gray, flaggy sandstones, with some blue shale, 1,700 feet.

Chemung Epoch. — Vergent" gray, red, and olive shales, with gray and red sandstones, 3,200 feet.

CATSKILL. — "Ponent" red sandstone and shale, with some conglomerate, 6,000 feet.

Carboniferous.

SUBCARBONIFEROUS, *Lower.* — "Vespertine" coarse. gray sandstones and siliceous conglomerate at the eastward, becoming fine sandstones and shales at the westward, 2,660 feet.

Upper. — "Umbral" fine red sandstones and shales, with some limestone, 3,000 feet.

CARBONIFEROUS, *Millstone-Grit Epoch.* — "Seral" siliceous conglomerate, coarse sandstone and shale, including coal-beds, 1,100 feet.

Coal-measures. — 2,000-3,000 feet.

2. *Ohio Section.*

Lower Silurian.

PRIMORDIAL, *Potsdam Epoch.* — Whitish calcareous sandstone, 316 feet or more — (at bottom of the "State House well").

CANADIAN, *Calciferous Epoch.* — Drab, sandy, magnesian limestone, 475 feet — (passed through in boring the "State House well").

TRENTON, *Trenton, Utica, and Cincinnati Epochs.* — Limestones and calcareous shales and marlytes, blue and green below, gray, brown, and red above, 1,220 feet, (the lower 250 found only in deep borings.)

Upper Silurian.

NIAGARA, *Clinton Epoch.* — Cream to salmon-colored, semi-crystalline, crinoidal limestone, 10 to 40 feet.

Niagara Epoch. — Shales, 60 to 100 feet, overlaid by buff and blue arenaceous and magnesian limestones, 90 to 180 feet.

Salina Epoch. — Limestones, with beds of gypsum, 1 to 16 feet.

LOWER HELDERBERG. — "Waterlime" group: gray and yellow, coarse-grained and massive limestones, 70 to 100 feet.

ORISKANY, *Oriskany Epoch.* — Coarse saccharoidal sandstone, 3 to 10 feet.

Devonian.

CORNIFEROUS, *Corniferous Epoch.* — Buff massive limestone, 15 to 100 feet.

HAMILTON, *Hamilton Epoch.* — Bluish marly limestone, 10 to 20 feet near Sandusky, elsewhere wanting.

Genesee Epoch. — Black, bituminous "Huron" shale, with numerous large calcareous concretions, 250 to 330 feet. Partly Portage?

CHEMUNG, *Portage Epoch.* — *Chemung Epoch.* — "Erie" green, gray, and blue shales, with few thin layers of sandstone and limestone: 1,000 feet in the eastern counties, 500 to 400 in the central ones, and thinning southward until no longer recognized.

Carboniferous.

SUBCARBONIFEROUS, *Lower.* — "Waverly" shales and sandstones; in the northern counties, 320 feet; 640 feet, on the Ohio River.

Upper. — "Maxville" limestone, 10 to 20 feet.

CARBONIFEROUS, *Millstone Grit Epoch.* — Conglomerate and sandstones, 10 to 130 feet.

Coal-measures. — Shales, sandstones and limestones, with bands of iron ore and twelve workable seams of coal, 2,000 feet.

3. *Michigan (Lower Peninsula) Section.*

Lower Silurian.

PRIMORDIAL. — No formation certainly identified.

CANADIAN. — "Lake Superior" sandstone, mottled, reddish, or dark and shaly, at Sault St. Mary, 18 feet; more to the westward, 250 feet.

TRENTON, *Trenton Epoch.* — Blue argillaceous limestone, with shale, 30 feet.

Cincinnati Epoch. — Argillaceous limestone, bluish-gray below, 18 feet or more.

Upper Silurian.

NIAGARA, *Clinton Epoch.* — Argillaceous and calcareous limestones, 51 feet.

Niagara Epoch. — White and gray limestones, 97 feet.

SALINA, *Saliferous Epoch.* — Brown and gray argillaceous limestones, calcareous clay, and variegated gypseous marls, 37 feet.
ORISKANY, *Oriskany Epoch.* — Cherty, sometimes agatiferous conglomerate, 3 feet.

Devonian.

CORNIFEROUS, *Corniferous Epoch.* — Brecciated limestone, 250 feet; overlaid by oölitic, arenaceous, and bituminous limestones, 104 feet.

HAMILTON, *Marcellus (?) Epoch.* — Black, bituminous limestone, 15 feet.
Hamilton Epoch. — Argillaceous limestones, 17 feet; crystalline limestone, with included lenticular clayey masses, 23 feet; total, 40 feet. Contains a bed of coal, on Little Traverse Bay.
Genesee (?) Epoch. — Black, bituminous shale, 20 feet.
CHEMUNG, *Portage Epoch.* — "Huron" shales, 190 feet.

Carboniferous.

SUBCARBONIFEROUS, *Lower.* — "Huron" and "Marshall" grit-stones, and reddish, yellowish, and greenish sandstones and conglomerates, 173 feet; "Napoleon sandstone," generally micaceous, with clay beneath, 123 feet; "Michigan Salt-group," carbonaceous and argillaceous shales, magnesian and arenaceous limestones, and thick beds of gypsum, 184 feet; total, 480 feet.
Upper. — Limestones, arenaceous below, 66 feet.
CARBONIFEROUS, *Millstone Grit Section* — "Parma" thick-bedded sandstone, in some places conglomerate, 105 feet.
Coal-measures. — Bituminous shales and fire-clays, with occasional thin sandstones and limestones, 123 feet; "Woodville" sandstone, 79 feet; total, 202 feet.

4. *Iowa Section.*

Lower Silurian.

PRIMORDIAL, *Potsdam Epoch.* — Sandstone, with thin, calcareous layers, 200 feet.
CANADIAN, *Calciferous Epoch.* — "Lower Magnesian" limestone, 250 feet.
Chazy Epoch. — "St. Peter's Sandstone," 80 feet.
TRENTON, *Trenton Epoch.* — "Buff," "Blue," and "Galena" magnesian limestones, with some shaly portions in the lower layers, 450 feet.
Cincinnati Epoch. — Siliceous and argillaceous "Maquoketa" shales, mostly bituminous, 80 feet.

Upper Silurian.

NIAGARA, *Clinton and Niagara Epochs.* — Light yellowish-gray, compact magnesian limestone, with much chert, 350 feet.

Devonian.

HAMILTON, *Hamilton Epoch.* — Shales and magnesian limestones, 200 feet.

Carboniferous.

SUBCARBONIFEROUS. — Consisting of — 1st, "Kinderhook" beds, 175 feet; 2d, "Burlington" limestone, 190 feet; 3d, "Keokuk" limestone, with thin beds of shale, 90 feet; 4th, "St. Louis" limestone, commonly brecciated and concretionary, in some parts compact, 75 feet; total, 530 feet.
CARBONIFEROUS. — Lower Coal-measures, 200 feet; Middle, 200 feet; Upper, 200 feet.

5. *Illinois Section.*

Lower Silurian.

CANADIAN, *Calciferous Epoch.* — "Lower Magnesian limestone," 100 to 120 feet.
Chazy Epoch. — "St. Peter's" sandstone, 150 feet.
TRENTON, *Trenton Epoch.* — "Trenton" and "Galena" brown magnesian limestones, 200 to 300 feet.
Cincinnati Epoch. — Shales, shaly sandstones, and dark-blue limestone, 60 to 250 feet.

Upper Silurian.

NIAGARA. — Buff and gray magnesian limestone, some cherty beds, 250 to 300 feet.
LOWER HELDERBERG? — "Clear Creek" limestone, 300 to 350 feet.
ORISKANY. — Quartzose sandstone, becoming locally calcareous, 50 feet.

Devonian.

CORNIFEROUS? — Limestone, 10 to 120 feet.
HAMILTON, *Hamilton Epoch.* — "Black shale," 30 to 60 feet.

Carboniferous.

SUBCARBONIFEROUS. — Consisting of — 1st, "Kinderhook" group, 100 to 150 feet; 2d, "Burlington" limestones, with chert, 25 to 200 feet; 3d, "Keokuk" group, 100 to 150 feet; 4th, "St. Louis" group, 50 to 200 feet; 5th, "Chester" group, 500 to 800 feet.
CARBONIFEROUS, *Millstone Grit and Coal-measures*, 600 to 1,200 feet.

6. *Missouri Section.*

Lower Silurian.

CANADIAN, *Calciferous and Quebec Epochs.* — "Lower Magnesian" limestones, 1,300–1,500 feet.
TRENTON, *Trenton Epoch.* — Bluish-gray and drab compact limestone, and some blue shale, 435 feet; overlaid by "Receptaculite" argillaceous subcrystalline limestone, 130 feet; total, 565 feet.
Cincinnati Epoch. — Two beds of argillaceous magnesian limestone, 60 feet, separated by shales, 60 feet; total, 120 feet.

Upper Silurian.

NIAGARA, *Niagara Epoch.* — Magnesian and argillaceous limestone, 150 feet.
LOWER HELDERBERG. — Light-gray magnesian limestone, 100 feet.
ORISKANY. — Light-gray, nearly pure limestone, — thickness not given.

Devonian.

CORNIFEROUS. — Gray, compact, earthy limestone, with chert and some sandstone; in some parts, a hard white oölyte, 75 feet.
HAMILTON, *Hamilton Epoch.* — Blue argillaceous shale, with thin layers of concretionary limestone, 50 feet.
Genesee Epoch. — "Black shale," 6 feet.

Carboniferous.

SUBCARBONIFEROUS. — 1st, Light-drab, fine-grained, compact, "Lithographic" siliceous limestone, 70 feet; 2d, buff sandstone, with some magnesian limestone,

underlaid by shale, 100 feet; 3d, fine-grained, compact limestone, overlaid by brown silico-magnesian limestone, 70–120 feet; 4th, "Encrinital," brown, buff, gray and white, coarse crystalline heavy-bedded limestones, everywhere containing chert, 500 feet; 5th, "Archimedes" gray and drab, crystalline and compact limestones, with some silico-argillaceous limestones and blue shales, 200 feet; 6th, "St. Louis" hard, crystalline, gray, cherty limestone, with thin beds of argillaceous shale, 250 feet; 7th, "Ferruginous" brown and red, coarse, friable sandstone, in some parts white and "saccharoidal," 200 feet: total, 1,150 feet.

CARBONIFEROUS, *Coal-measures.* — Blue and gray compact limestones, with black, blue and purple bituminous and calcareous shales, and a few thin beds of coarse sandstone, 2,000 feet or more.

7. *Tennessee Section.*

Lower Silurian.

PRIMORDIAL, *Acadian Epoch* (?). — "Ocoee" slates and conglomerates, 8,000 to 10,000 feet.

Potsdam Epoch. — "Chilhowee" sandstones and sandy shales, at least 2,000 feet in *East Tennessee.*

CANADIAN, *Calciferous and Quebec Epochs.* — "Knox Group," fine-grained sandstones and shales, with magnesian limestone: sandstone member (lowest), 800–1,000 feet in *East Tennessee;* shales, 1,500–2,000 feet; limestone, 3,500 to 4,000 feet.

TRENTON, *Trenton Epoch.* — Blue and dove-colored limestones, gray and mottled marbles and shales, 1,500–2,000 feet in *East Tennessee;* Trenton and lower part of "Nashville Group," 500 feet in *Middle Tennessee.*

Utica and Cincinnati Epochs. — Upper part of "Nashville Group," calcareous shales and argillaceous limestones, including beds of fine marble, 500–1,000 feet in *East Tennessee;* 500 feet in *Middle Tennessee.*

Upper Silurian.

NIAGARA, *Medina Epoch.* — "Clinch Mountain" white and gray sandstone, and "White Oak Mountain" brown sandstones and shales, 800–1,000 feet.

Clinton Epoch. — "Dyestone Group," variegated calcareous shales, with some sandstone and bands of "dyestone" iron-ore, 100–300 feet in *East Tennessee.*

Niagara Epoch. — "Meniscus" gray limestone, 150–200 feet.

LOWER HELDERBERG. — Gray crinoidal limestone, 75–100 feet in *Middle Tennessee;* absent elsewhere (?).

Devonian.

HAMILTON (?), *Genesee Epoch.* — "Black shale," a brownish-black shale, often pyritiferous and bituminous, with a layer of phosphatic nodules at top, and a dark gray, fine-grained bituminous fetid sandstone at bottom, 100 feet or more.

Carboniferous.

SUBCARBONIFEROUS, *Lower.* — "Siliceous Group," shales and sandstone, varying to blue and gray limestones, mostly cherty, with some shale, 300–550 feet.

Upper. — "Mountain" limestone, blue, thick-bedded, and in great part oölitic, 500–700 feet in *Middle Tennessee.*

CARBONIFEROUS. — Sandy conglomerates, sandstones and shales, with six or more workable coal-beds, 2,500 feet or more.

In the *Eastern-border region*, about the Gulf of St. Lawrence (which was probably an interior basin like the Interior Continental), there were limestones forming almost continuously, from the Calciferous epoch in the Lower Silurian to the close of the Clinton epoch in the Upper Silurian, which is the last of the formations there observed. With regard to other parts of the Eastern-border region, our knowledge is yet imperfect, and in great measure because the crystallization which the rocks have undergone has obliterated most of their original features. This is the case over New England and the border of the continent south of New York. Besides this, a strip of land some eighty miles wide, constituting the eastern margin of the continental plateau, is still under water (p. 11). The map, Fig. 735, gives a general view of the breadth and depth of this plateau, off the coast of New Jersey.

3. *Diversities in the different regions as to the thickness of the rocks.* — The maximum thickness of the North American Paleozoic rocks is 55,000 feet. About 45,000 feet of this thickness occur in the Appalachian region of Pennsylvania, the rest being made up by the excess of the Carboniferous formation in Nova Scotia. All this 45,000 feet is not found in any one place; for some of the formations are thickest along the middle of the region, others on the western side, and still others on the eastern. The general thickness over the Appalachian regions is 40,000 feet, according to Hall. Each of the successive formations in the Appalachian region is remarkable for its great thickness, from the Potsdam upward.

In the central portions of the Interior Continental basin, the thickness varies from 3,500 (and less on the north) to 6,000 feet. It is, therefore, from *one seventh* to *one twelfth* that in the Appalachian region.

Another region of unusual thickness lies on the north side of the Interior basin, near the Archæan. Along Lakes Superior and Huron, the fragmental Huronian beds of the closing part of the Archæan age accumulated to a thickness of 10,000 to 20,000 feet; and, in the course of the Canadian period, the sedimentary beds, in some places about the former lake, reached a thickness of 3,000 to 4,000 feet. Again, in the region of the St. Lawrence, about Ottawa, the Potsdam beds have *twice* the thickness they exhibit in the State of New York; and the Trenton beds in Canada are *three* times as thick, or nearly 1,000 feet.

In Missouri, during the Calciferous and Quebec epochs, the accumulations had the great thickness of 1,300 feet, — an exception to the usual fact in the Interior Continental region.

4. *Relative duration of the Paleozoic ages.* — The thicknesses of

the series of rocks pertaining to the several ages affords some data for estimating their *time-ratios.* The results are necessarily uncertain, since the increase of a rock is often directly connected with the subsidence there in progress, as has been elsewhere explained. Still, the conclusions are sufficiently reliable to be here presented.

Taking the maximum thickness, along the Appalachians, of the successive formations (the limestone and fragmental beds in each case from the same region), we find for the

	Fragmental rocks.	Limestones.
1. Potsdam period	7,000	200
2. Rest of Lower Silurian . . .	18,000	6,000
3. Lower Silurian era	25,000	6,200
4. Upper Silurian era	6,760	600
5. Devonian Age	14,300	100
6. Carboniferous Age	16,000	125

Limestones increase with extreme slowness, as explained in the chapter on coral islands. From five to ten feet of fragmental deposits will accumulate while one of limestone is forming. This conclusion is sustained by the ratio, in any given period, between the fragmental rocks of the Appalachians and the limestones of the Interior basin.

Taking the ratio as 5 to 1, and making the substitution accordingly, the numbers are, respectively, (1) 8,000; (2) 48,000; (3) 56,000; (4) 9,760; (5) 14,800; (6) 16,625. These numbers have nearly the ratio $1:6:7:1\frac{1}{4}:2:2$. Hence, for the Silurian, Devonian, and Carboniferous ages, the relative duration will be $8\frac{1}{4}:2:2$, or not far from $4:1:1$. Or, the Silurian age was *four* times as long as either the Devonian or Carboniferous; and the Lower Silurian era nearly *six* times as long as the Upper Silurian.

In the Silurian age, the ocean worked almost alone, in the wear and accumulation of rock material, while in the Carboniferous, at least about Nova Scotia, where the Carboniferous rocks are nearly three times as thick as elsewhere, river-action aided greatly in the result. Hence the ratio $4:1:1$ would seem to give the relative length of the Carboniferous age too high. Yet, as the eras of the several coal beds must have been each of great length, the ratio can hardly need change on this account.

II. Life.

1. *System of progress.* — The Animal kingdom began with Protozoans, then followed Radiates, Mollusks, and water-Articulates; it included Fishes, the lower Vertebrates, in the closing Silurian; and Amphibian species in the commencing Carboniferous age. With each period, the progress was upward, toward a fuller and higher display of the system of life, though not beginning always in the lowest species of a group.

It is important to observe, in this connection, that the length of the Age of Invertebrates, or Silurian age, as just shown, was at least four times that of either the Devonian or the Carboniferous.

The following are some of the principles bearing on the progress of life, which have been exemplified in Paleozoic history.

(1.) *The earlier species were aquatic, and all of them marine.*

Protozoans, Radiates, Mollusks, and the water-Articulates, comprise all known species of animals, and Sea-weeds all the fossil plants, to the close of the Lower Silurian; and the Upper Silurian adds only Fishes, or aquatic Vertebrates, and terrestrial Cryptogams. In all divisions of the kingdoms of life, the species made for the water are of inferior grade. As already stated, there were probably exceptions, in the existence of Lichens and Fungi even before the Silurian, and of Insects and Spiders before the Devonian; but direct proof of this is wanting.

(2.) *Many of the earlier types were comprehensive types*, that is, they combined the characteristics of two or three groups of the same or later time. Thus, the *Brachiopods*, the most common of all the kinds of life, combined characteristics of both the Mollusks and the Worms, and so decidedly that a recent writer, Mr. E. S. Morse, takes the ground that they are more closely related to Worms than to Mollusks.

Crinoids, and especially the *Cystids*, combine the flexible arms of *Starfishes* with much of the box-like structure and other characters of *Echini*. *Trilobites* have intermediate characters between those of Crustaceans and the Scorpions among Spiders (Verrill), although most closely approaching the former of these groups.

Neuropterous Insects of the Devonian and Carboniferous eras were in general not purely Neuropters, but combined characters of Orthopters also, showing it in their wings and other parts, one even having a stridulating arrangement, which at present is peculiarly the property of Orthopters.

Ganoid fishes were called *Reptilian* fishes by Agassiz, they having the teeth like those of the ancient Labyrinthodonts, a cellular air-bladder approximating to a lung, and a flexible articulation between the head and neck — points not known among the ordinary Osseous fishes.

The *Cephalaspids*, the earliest Ganoids, were intermediate in some respects between Ganoids and the Sharks, the other fishes of the Devonian.

The *Amphibians* of the Carboniferous were mainly if not wholly *Labyrinthodonts*, species that, along with the ordinary characters of the Amphibians, had the scaly skin, strong teeth, etc., of Lizards or true Reptiles.

The *Lepidodendrids* of the Coal era, while true Acrogens, have the

aspect and foliage of the Pine tribe. The Cycads have the habit of foliage nearly of a Palm, the vernation of a Fern, the leaf uncoiling in its development, along with the wood, flowers, and fruit, and hence the essential structure, of a Conifer.

Thus it was true of many of the grand divisions that they embraced a wider range of characters than belongs to the divisions which afterward appeared. In some cases, these comprehensive types occurred along with the groups of which they were in a sense the combination, as in the case of the Lepidodendrids with the Ferns and Pine-tribe, during the Devonian and Carboniferous ages. In other cases, they were prophetic of one or two groups yet to exist, as with the Ganoids, which foreshadowed reptile life long before it appeared, and also the purer fish type.

3. *Many of the Paleozoic species were much larger than later species of the same groups.* Among *Crustaceans*, there were Trilobites larger than any living Crustacean; species of the Eurypterus group five feet long, while the nearest existing species are not a foot long; Ostracoids of ten times the length and a thousand times the bulk of modern kinds; and so also with the Phyllopods.

Among *Insects*, there were Neuropters whose wings were over three inches long and two wide, vastly beyond the size of any recent May-fly. Among *Fishes*, there were Sharks at least thirty feet long, or near the size of the largest living species. The ancient *Amphibians* were gigantic, compared with the frogs and salamanders of the present day; the earliest known had its fore-foot *four inches broad.* Among *Plants*, the ancient Lepidodendrids were great trees; while the modern Lycopodia, to which they are related, are two feet or less in height.

Trilobites, Phyllopods, Ostracoids, Eurypterids, etc., made their grandest display in the Silurian and Devonian ages, and Cryptogamous plants their best in the Carboniferous age.

4. *Many of the Paleozoic species were multiplicate forms*, the body containing more than the normal number of divisions. In normal Crustaceans, the number of segments, or rings, of which the thorax and abdomen consist, is fourteen; but, in the great majority of the Paleozoic species, including all the Phyllopods and many of the Trilobites, the number was indefinite. Again, in the Echinoids, of Post-carboniferous time, the number of vertical series of plates was more than twenty, the normal number.

5. *Very many of the earlier Paleozoic animals were fixed species with stems or other mode of attachment, like flowers.* The Crinoids are examples among Echinoderms; the Graptolites, among Acalephs; the Corals, among Polyps; Bryozoans and Brachiopods, among Mollusks;

and these made up a very large part of the animal life of the Lower Silurian.

6. *Harmony in the life of an era.* — The forests of the Devonian and Carboniferous were made up of Acrogens, or the highest of Cryptogams, and Conifers, the lowest of Phenogams; and among the former there were the pine-like Lepidodendrids and Sigillarids, having the foliage of the Conifers, and somewhat also of their form of fructification. In the Silurian, when the bivalved Mollusks were the most abundant of species, Ostracoids, or bivalve Crustaceans, were also exceedingly common.

7. *Exterminations.* — At the close of each *period* of the Paleozoic ages, there was an extermination of a large number of living species. Again, as each *epoch* terminated, there was an extermination of life, but in most cases less general. With the transitions between strata of different kinds, in the course of an epoch, there were usually some exterminations; and, even in the passage from layer to layer, there is often evidence of the extinction of some species. In a corresponding manner, there were often one or more new species with each new kind of layer, and generally several with each change in the strata; while many appeared with the opening of an epoch, and a whole fauna, nearly, with the commencement of a period. Hence, the introduction and extinction of species were going on through the whole course of the history, instead of being confined to particular points of time; but, at the close of long periods and epochs, there were more general exterminations. As the rocks from which the facts come are Continental rocks, the conclusion with regard to the completeness of exterminations cannot be regarded as applying necessarily to the life of the deeper parts of the ocean.

8. *Extinction of whole tribes, families, or genera of species.* — Among the tribes of land-plants of the Carboniferous age that became extinct at its close, there are those of the *Sigillarids* and *Lepidodendrids.*

The races of animals that were most prominent in giving a special character to the Paleozoic fauna were the following: —

Among *Radiates*, Crinoids and Cyathophylloid Corals; among *Mollusks*, Brachiopods and Orthocerata; among *Articulates*, Trilobites; among *Vertebrates*, the vertebrate-tailed Ganoid fishes. Of these, the group of Trilobites became extinct with the close of the Paleozoic, and the vertebrate-tailed Ganoids very nearly so; and Cyathophylloid Corals, Crinoids, Brachiopods, and Orthocerata lost their preëminence in numbers of species and individuals, in their respective sub-kingdoms.

The following are a few other examples of the last appearance among fossils of prominent Paleozoic groups: —

Graptolites, which culminated in the Lower Silurian, became rare before the close of the Upper Silurian, and ended with the Carbonif-

erous; *Cystideans*, which culminated also in the Lower Silurian, and had their last species in the early Devonian, though not their last species in fact, since the depths of the Pacific Ocean still contain Cystids; *Goniatites*, which began in the Hamilton period of the Devonian, and are unknown after the Carboniferous age. Many other instances are given in the table beyond. The causes of such extinctions were connected with a higher principle than that of mere physical catastrophe.

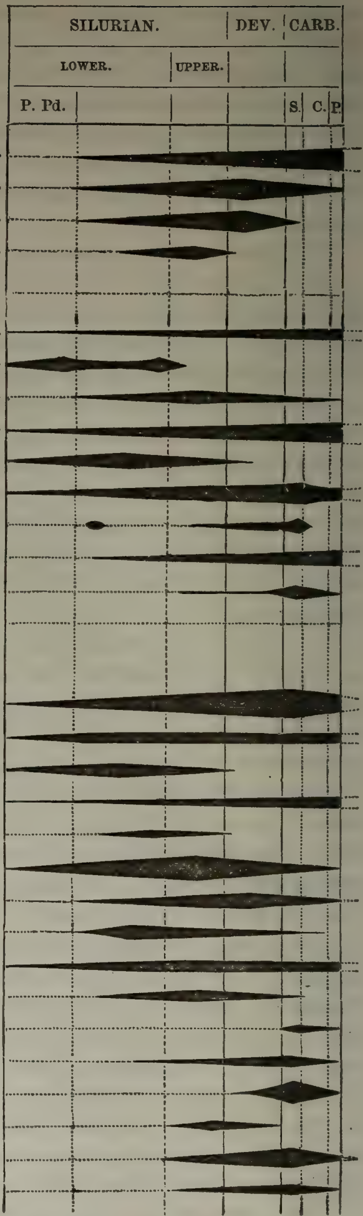
The following table presents to the eye the history of many of the genera, families, and tribes of Paleozoic species, showing, by means of the narrow dark areas, the time of their commencement; the time of their culmination (by the greatest breadth of the area); and the time of their extinction in the course of the Paleozoic ages, or the fact of their continuing to survive in after-time. Thus, opposite the word *Polyps*, the area commences near the beginning of the Silurian, and increases through the Paleozoic, but does not terminate there, since they exist afterward; the *Cyathophylloid* Corals begin with the Lower Silurian, have their maximum in the Devonian, and only a few are known after the Carboniferous. At the top of the columns, P. Pd. stands for Primordial Period; and S., C., P., for Subcarboniferous, Carboniferous, and Permian.

9. *Genera of the present time dating from the Paleozoic era.* — The number of lines connecting the past with the present is considerably increased in the Carboniferous age. These lines are, however, only long-lived genera, not species. The following are those which appear to be determined with a good degree of certainty: —

Lingula (?), *Discina*, *Crania*, *Nautilus*, *Pleurotomaria*, *Rhynchonella*, *Terebratula*, *Ostrea*, *Avicula*, *Pinna*, *Lima*, *Solemya*, *Leda*, *Nucula*, *Dentalium*, *Chiton*. They are all Molluscan. The first five commenced in the Lower Silurian. It is to be acknowledged that there may have been greater differences between the existing and modern species of these genera than the shells have given reason to suspect. In view of this, the older *Lingulæ* have been of late called *Lingulellæ*, sufficiently great differences existing to excite the belief that the animals were generically different. It is a remarkable fact that there are no Radiate genera in this list.

Besides the above, the genera *Arca* and *Astarte* have been referred to the Paleozoic; but the species probably belong to other genera. There are no genera of Articulates, unless it be the genus *Spirorbis*, about which there is reason for much doubt.

There are modern genera of Protozoans in the Paleozoic, and probably also of Diatoms; and the number of such genera among these protozoan and protophyte forms will probably be greatly increased, when the species are further investigated.



RADIATES.

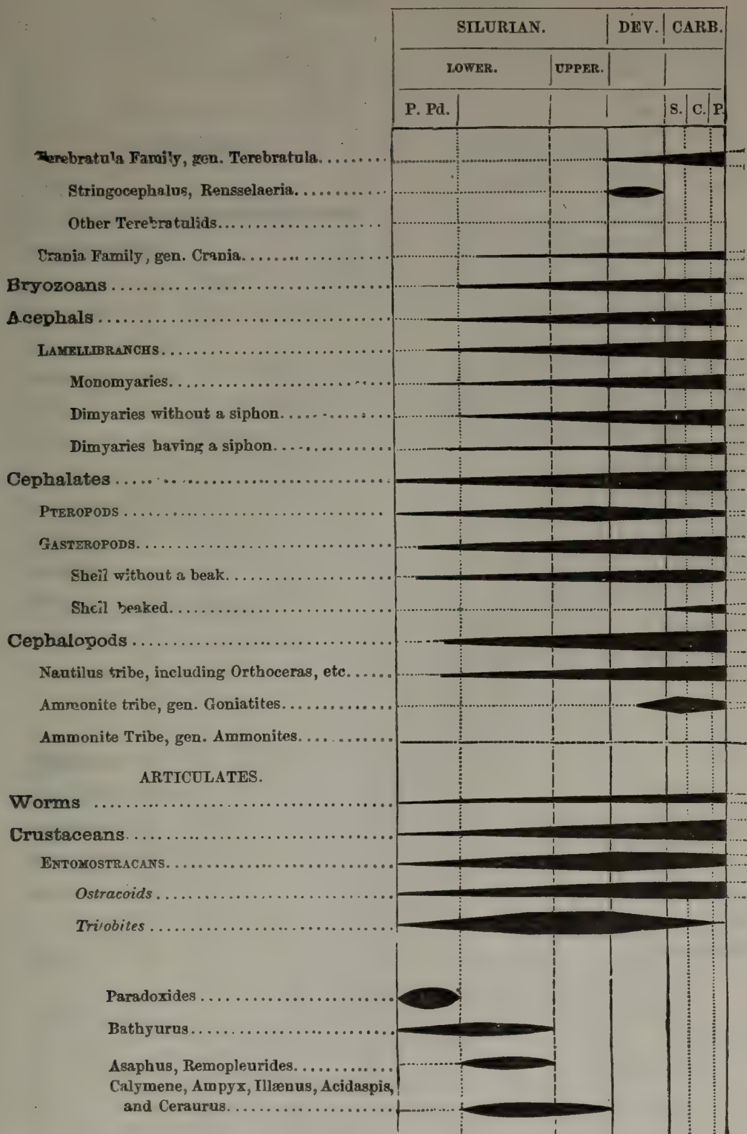
Polyps
- Cyathophyllum Family
- Favosites, of the Madrepore Tribe
- Halysites
- Oculina Tribe
- Astræa Tribe

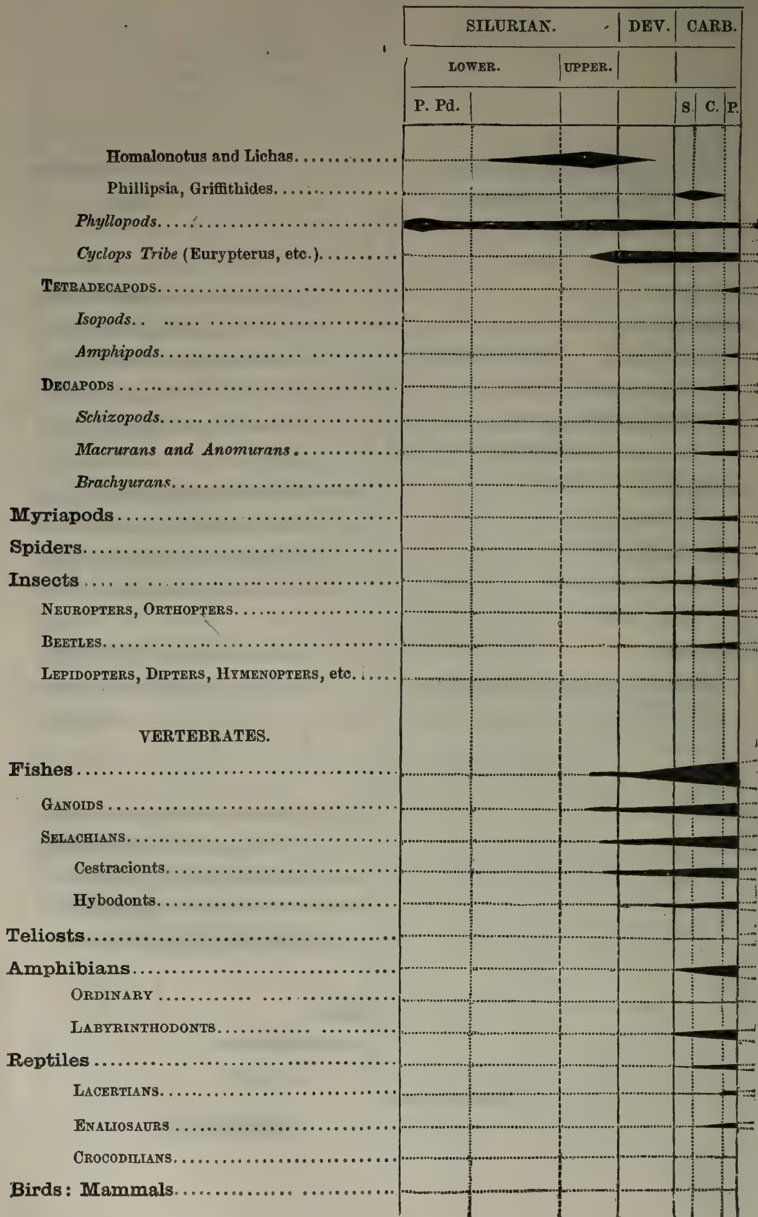
Acalephs
- Graptolites
- Chætetes

Echinoderms
- Cystideans
- Crinideans
- Blastideans (Pentremites, etc.)
- Star-fishes
- Palæechinoids (including Archæocidaris)
- Cidaris, Spatangids, etc.

MOLLUSKS.

Brachiopods
- Lingula Family, gen. Lingulella
  - Obolus, Obolella
- Discina Family, gen. Discina
  - Siphonotreta
- Orthis Family, gen. Orthis
  - Leptæna
  - Strophomena
- Rhynchonella Family, gen. Rhynchonella, etc.
  - Pentamerus
  - Camarophoria
- Productus Family, gen. Chonetes
  - Productus
- Spirifer Family, gen. Atrypa
  - Spirifer
  - Athyris


SILURIAN.
DEV.
CARB.
LOWER.
UPPER.
P. Pd.
S.
C.
P.
Terebratula Family, gen. Terebratula
Stringocephalus, Rensselaeria
Other Terebratulids
Crania Family, gen. Crania
Bryozoans
Acephals
LAMELLIBRANCHS
Monomyaries
Dimyaries without a siphon
Dimyaries having a siphon
Cephalates
PTEROPODS
GASTEROPODS
Shell without a beak
Shell beaked
Cephalopods
Nautilus tribe, including Orthoceras, etc.
Ammonite tribe, gen. Goniatites
Ammonite Tribe, gen. Ammonites
ARTICULATES.
Worms
Crustaceans
ENTOMOSTRACANS
Ostracoids
Trilobites
Paradoxides
Bathyurus
Asaphus, Remopleurides
Calymene, Ampyx, Illænus, Acidaspis, and Ceraurus


SILURIAN.
DEV.
CARB.
LOWER.
UPPER.
P. Pd.
S.
C.
P.
Homalonotus and Lichas
Phillipsia, Griffithides
Phyllopods
Cyclops Tribe (Eurypterus, etc.)
Tetradecapods
Isopods
Amphipods
Decapods
Schizopods
Macrurans and Anomurans
Brachyurans
Myriapods
Spiders
Insects
Neuropters, Orthopters
Beetles
Lepidopters, Dipters, Hymenopters, etc.
VERTEBRATES.
Fishes
Ganoids
Selachians
Cestracionts
Hybodonts
Teliosts
Amphibians
Ordinary
Labyrinthodonts
Reptiles
Lacertians
Enaliosaurs
Crocodilians
Birds: Mammals

III. American Geography.

1. *General course of progress.* — Through the Paleozoic ages, the dry land of the closing Archæan age (map on p. 149) gradually extended southeastward, southward, and southwestward. At the end of the Silurian, the limit of the dry land appears to have crossed New York, near the central east-and-west line of the State; and, at the close of the Devonian, it lay not far from its southern border. Westward, beyond Michigan, in Illinois, Iowa, and Minnesota, there was a like expansion to the south and west of the Wisconsin Archæan. Michigan long continued to be a part of the oscillating Interior basin, the Paleozoic formations being continued there, even to the close of the Coal period.

Along the St. Lawrence, the Ottawa basin was nearly obliterated at the close of the Lower Silurian (p. 215). At the same time, the folding and crystallization of the rocks of the Green Mountains, — the northern portion of the Appalachian chain, — took place; and the region of the mountains became dry land, and part of the *terra firma* of North America. In the latter half of the Upper Silurian, the river opened into a St. Lawrence gulf over the site of Montreal, and a Lower Helderberg limestone was formed in its waters, upon the upturned Lower Silurian. The same waters extended southward along Lake Champlain and the Hudson River valley; and in them Lower Helderberg limestones were formed, on both sides of the Hudson River. In the Devonian age, the head of the St. Lawrence gulf was probably in the vicinity of Quebec, and opened southward over central New England; for coral reefs were growing in the region of Lake Memphremagog, and in the Connecticut valley, at Littleton, N. H., during the earlier Devonian (p. 256); and Crinoids in the same valley, in Massachusetts (p. 237), in the Lower or Upper Helderberg era.

Still farther south, over part of Rhode Island, lay the Carboniferous marshes or coal-making area of the New England basin; while, to the northeast, over part of Nova Scotia and New Brunswick, the region of the St. Lawrence Gulf, and bordering portions of Newfoundland, there were the far larger marshes of the Acadian basin. The two belong geographically to the same great region — then low — between the St. Lawrence and the ocean, but were probably in part separated by the Archæan rocks of northeastern Massachusetts.

At the same time, over the rest of the continent, the dry land had expanded nearly to its present extent, and became covered with forests, jungles, and marshes of Carboniferous vegetation. This condition oscillated with that of marine submergence, many times in the progress of the Coal period. But the dry land appears to have reached

a degree of permanence, in the Appalachian region, after the Pittsburg Coal series, and to a still wider extent, throughout the whole interior east of the Mississippi, after the Upper Coal beds (p. 368); so that, when the Carboniferous period closed, the continent in this its eastern half was almost complete. Over the whole surface, including New England, Canada, and the British possessions eastward, no rocks occur between the Paleozoic and Cretaceous, excepting small strips of Mesozoic in the Eastern-border region, *east* of the Alleghanies, and also in the Connecticut valley and Nova Scotia.

The interior sea, which in Silurian and Devonian periods had spread from the Gulf of Mexico over the whole Interior Continental basin, and northward on the west side of the Archæan nucleus to the Arctic Ocean, after many variations eastward and westward in its extent through the whole Paleozoic, was at last mostly limited to the region west of the Mississippi; for here are located all the marine sedimentary deposits of the Interior, formed in later time.

2. *Mountains.* — The mountains of the Paleozoic continent were mainly those of the Archæan, — the Adirondack, of northern New York; other heights, in British America; ridges in the line of the Highlands of New Jersey, and the Blue Ridge of Virginia; probably the Black Mountains of North Carolina; the Black Hills, Wind River Mountains, and other ridges in the seas of the Rocky Mountain region, etc. The Carboniferous marshes covered a large part of the site of the Alleghanies; and a sea, in which Carboniferous limestones were forming, a considerable portion — perhaps all but the Archæan heights — of the area of the Rocky Mountains.

Moreover, after the close of the Lower Silurian, the Green Mountain region appears to have been above the sea (pp. 212, 305), and divided the New England or Eastern-border region from the Interior. Consequently, the subsequent progress of the dry land over New England was from the Green Mountain region eastward, as well as from the St. Lawrence southward. In other words, the Devonian beds, which stretch from Gaspé to Vermont, stretch also over much of Maine. But nearly all the interior of New England was probably dry land, after the close of the Lower Devonian, since rocks of the Upper Devonian are confined to the Atlantic border of Maine and New Brunswick. At the close of the Devonian, another mountain-making epoch passed over the Eastern-border region (p. 289); and probably the upturning and crystallization of the Devonian and Upper Silurian rocks of New England, as well as of Eastern Canada, Nova Scotia, and New Brunswick, dates from this time.

3. *Rivers.* — The rivers of the early Paleozoic were only small streams, such as might have gathered on the limited Archæan lands.

In the later Devonian and the Carboniferous, they included the Hudson and St. Lawrence (p. 287), and probably, during the Carboniferous, the Connecticut. But, even to the last, the region of the great streams of the Rocky Mountains was still a part of the interior sea; the Mississippi had but a part of its length, and this only temporarily, as the country was often submerged. The valley of the Ohio River was in part the region of the interior Carboniferous marshes: as the mountains in which it rises were not yet raised, the river cannot have existed. Moreover, the Cincinnati uplift (p. 211), which stretched southwestward into Kentucky and Tennessee, and may date from the beginning of the Upper Silurian, probably divided the great interior marshes about the upper Ohio region from those of the lower.

IV. Oscillations of level. — Dislocations of the strata.

1. *General subsidence.* — The earliest Silurian beds, in the Appalachian region and New York, — the Primordial, — bear abundant proof, in ripple-marks, sun-cracks, and wind-drifts, of their formation near the water-level. Many of the succeeding strata of the Silurian and Devonian periods contain the same evidence, and lead to the same conclusion for each; and later, in the Carboniferous formation, many layers show in a similar manner that they were spread out by the waves, or within their reach. Consequently, when these last layers of the Paleozoic in the Appalachian region were at the ocean's level, the Potsdam beds — though once also at the surface — were about *seven* miles below (p. 380); for this is the thickness of the strata that intervene; seven miles of subsidence had, therefore, taken place in that region, during the progress of the Paleozoic ages.

From analogous facts, it is learned that the subsidence in the Interior Continental basin may not have exceeded one mile. In the lower peninsula of Michigan, measuring it by the thickness of the rocks, it was at least 2,500 feet; in Illinois, 3,000 to 4,000 feet; in Missouri, 5,000 to 6,000 feet.

On the northern border of the Interior basin, near the Archæan, the thickness of the Lower Silurian indicates a great subsidence in that era, which was not afterward continued. Thus, in the vicinity of the Great Lakes, the 10,000 or 20,000 feet of the Huronian in the last part of the Archæan age, and the 4,000 of the early Lower Silurian, teach that, near the beginning of Paleozoic time, this was a region of unusual subsidence; and the igneous rocks that intersect and interlaminate the sedimentary strata evidently came up through the fractures that accompanied, or were occasioned by, the subsidence.

In Western Canada, between the stable Archæan of Canada and

New York, the 1,000 feet of Trenton limestone and 700 feet of Calciferous and Potsdam beds prove that there was a great subsiding also in that region, during the Lower Silurian, while little occurred on the south side of the New York Archæan region.

In Nova Scotia, the subsidence in the Carboniferous age alone was almost *three* miles, or nearly half the *seven* estimated for the Appalachians; and the question of such a subsidence is placed beyond doubt, by finding root-bearing clay-beds and coal-beds at different levels in the series, marking approximately the successive water-levels as the slow subsidence went forward.

All the numbers here given are probably below the actual fact; for the strata, in many cases, — especially along the Appalachian region — may have lost much of their original thickness by denudation, either before or after they were consolidated. This loss may have been one fourth the whole; but, whatever its extent, it probably has not altered the proportion of subsidence between the Appalachian region and the Interior.

2. *Oscillations.* — The successions of sandstones, shales, and limestones in the Paleozoic series have been explained to be indications of as many changes in the water-level of the continent. The prevalence of limestones over the Interior basin points out the region as an extensive reef-growing sea, opening south into the Atlantic by the Mexican Gulf region, and perhaps also into the Pacific, for the larger part of Paleozoic time. But there were slow oscillations in progress, that changed the limits of the formations to the eastward or westward, and northward or southward, as the periods succeeded one another.

Until the close of the Subcarboniferous period, the oscillations had that wide continental range which was eminently characteristic of the American Paleozoic. In the period following, the Carboniferous, the continent for prolonged periods stood raised just above the ocean, at a nearly uniform level, — so low that its interior was covered with immense fresh-water marshes, and for so long eras that the vegetable accumulations attained the thickness sufficient for great coal-beds (p. 358); but these emergences had their alternations with submergences. The system of oscillations, though slower in movement, was still continued; yet the movements were less general; and it is therefore difficult to make out a parallelism in the beds of coal and intervening rock-strata through the East and West.

3. *Uplifts and dislocations.* — The only mountain-region, along the course of existing chains, which can now be pointed to as having emerged during the Paleozoic ages, is that of the Green Mountains.

In Nova Scotia, New Brunswick, and parts of the St. Lawrence

valley and New England, there were dislocations of the strata and extensive uplifting at the close of the Devonian, making high ridges, but no true mountain range. But, in general, over the Continental Interior, and along the Appalachian region south of New York, the strata from the bottom of the Silurian to the top of the Carboniferous make an unbroken series, with no unconformability except the slight want of parallelism by overlap, which the great oscillations at times occasioned (p. 305). The extent of the series, and the vast length of time occupied by those passing ages, make this exemption from great disturbances a subject of profound importance in American geological history.

4. *Direction of Oscillations.* — The direction of the oscillations of the continent may be learned from the course of the region along which, through the successive periods, the greatest amount of change of level took place. One such region is the Appalachian, in which the subsidence, as has been shown, amounted in some parts to seven miles or more, while parallel with it, in the *Interior basin*, the average was comparatively small. The review of the limits of the successive formations, on p. 389, shows that even the minor changes took place under the influence of oscillations having this general course.

The Lower Silurian uplift, from Lake Erie to central Tennessee, conforms to this system. In accordance also with it, the Coal-measures in Pennsylvania, to the top of the Pittsburg series, were elevated, so that their marshes became dry, before the higher beds were laid down; and these upper beds, with the whole region west to the Mississippi, before the Permian (p. 368).

The Appalachian region lies parallel with one great branch of the Archæan dry land, C C, on map, p. 149, and also with the Atlantic Ocean. The Appalachian oscillations therefore conformed in direction with one of the two Archæan systems (p. 160): they were but a continuation of the series that prevailed while the Archæan age was in progress.

With regard to the region west of the Archæan, our information is yet scanty: sufficient, however, is known to make it apparent that the increase of dry land was from the Archæan to the southwest, or corresponding to oscillations parallel to the Rocky Mountains. The direct effect of such oscillations is manifest in the Illinois uplifts preceding the Coal-measures, for they are parallel to the Rocky Mountain chain and the Pacific coast-line. This, then, was a second grand direction of oscillations. It was parallel with the northwestern branch of the Archæan, B B, on map, p. 149, and corresponded to the second of the two series that prevailed during the Archæan age.

It is hence apparent that, whatever the forces at work in Archæan

time, they continued to act in the same general direction throughout the Paleozoic. The action of the two systems of forces together evidently produced the great amount of subsidence adjoining the Canada Archæan, where the thick deposits of the Huronian and Lower Silurian periods were formed, and where, finally, the basins of the Great Lakes were made. These and many other lakes of North America lie near the limit between the oscillating part of the continent and the stable Archæan area, and to this fact owe their formation.

5. *Cotemporaneous movements in the American and European continents.* — The fact that the continent of Europe was above the ocean, and in that condition which was characteristic of the Coal period, at the same time with North America, shows a cotemporaneousness in the oscillations of the crust on the opposite sides of the Atlantic Ocean. This concordance will be better apprehended, when it is considered that the land must have been but little elevated, and quite uniformly so, — enough to drain the great salt marshes of their salt, and not so high as to turn them into dry fields. It was not sufficient that there should be land and Carboniferous vegetation; for, without the wet, swampy lands, — wet with fresh waters, and very wide in extent, — the great accumulations of vegetation and immense coal fields would not have been made.

There is a similarity between the continents, also, in the character of the oscillations which occurred in the course of the Carboniferous period, which submerged the land after material for a coal bed had accumulated, and buried it for long keeping beneath sands, muds, or clays, and then brought it again to the surface for renewed verdure and another coal bed; and so on, in many successions.

The Millstone grit, which preceded the Coal-measures in Europe as well as America, is evidence of a degree of correspondence in that upward movement of the continents through the waves which ushered in the epoch of the Coal-measures; and the prevalence and wide distribution of the limestone of the Subcarboniferous period, which next preceded, mark another cotemporaneous movement, — a very general submergence, preceding the emergence just alluded to. Moreover, in both continents, some thin coal beds were formed in the Subcarboniferous period.

Contrast between America and Europe. — While the two continents were at times concordant in their general movement, there was apparently a contrast during the Coal period in the moisture of the two, which may in part, at least, be attributed to climate. This is apparent in the vastly larger coal fields of America. Guyot has called America the *forest-continent*, a character it now bears because of its moist climate, or more abundant rains; and it is probable that it presented this peculiarity with the first appearance of vegetation over its surface.

V. DISTURBANCES CLOSING PALEOZOIC TIME.

1. American.

An account of the Green Mountain revolution, closing the Lower Silurian, has been given on pages 212–216. In the succeeding eras, through the Paleozoic, — eras of prolonged quiet, — there were slow oscillations in progress over the continent, and, at the close of the Devonian, some great displacements of strata, producing metamorphism, in the northeast; but no upturning took place over the Appalachian region southeast of New England, until the Carboniferous age was approaching, or had reached, its end. This epoch of disturbance even rivalled that of the Middle Silurian, in the extent of the region involved, and forms a historical boundary between Paleozoic and Mesozoic time. The upturning after the Lower Silurian affected the Green Mountain region and some other parts of New England, folding and crystallizing the rocks, besides raising the mountains above the sea and adding them to the stable land of the Continent. In the disturbance closing the Paleozoic, all of the Appalachian region southwest of the Green Mountains was concerned; and the Alleghany Mountains were among the grand results. A portion of eastern New England, and of New Brunswick and Nova Scotia to the northeast, partook in the changes. It was a time of growth for the Continent; for, besides making the Appalachians, nearly all the region east of the Mississippi became part of the essentially stable land.

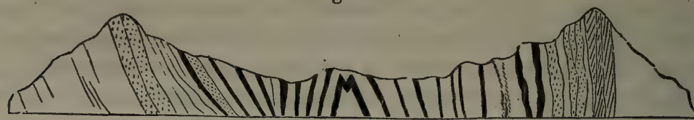
The effects of the disturbance were like those of the Silurian revolution. There were (1) *flexures and upturnings of the strata*; (2) *faults*; and (3) *alterations of rocks.*

1. Flexures. — The Coal-measures of Pennsylvania, Rhode Island, and Nova Scotia, which were originally spread out in horizontal beds of great extent, are now tilted at various angles, or rise into folds; and the strata are broken and faulted on a grand scale. Some of the folds are scores of miles in breadth, and are in many successions over the region, wave succeeding wave. Moreover, not only the Coal-measures, but the Devonian and Silurian, with, in some regions at least, part of the Archæan beds beneath, are involved together in this majestic system of displacements. The following facts on this subject are mainly from the Memoirs and Geological Reports of the Professors Rogers.

The general character of the flexures is illustrated in the annexed sections. Fig. 699 (by Taylor) is from the anthracite strata of the Mauch Chunk region, Pennsylvania. The great coal bed is folded and doubled on itself; and part of the inclosing strata are nearly vertical. In Fig. 700 (by Rogers), from Trevorton, Pa., the folding is of

a more gentle kind: eight coal seams are contained in this section, each of the dark lines representing one. These are examples of the

Fig. 699.



Section of the Coal-measures, near Nesquehoning, Pa.

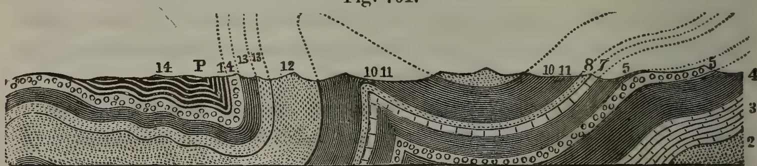
condition of the whole anthracite region. The patches into which it is divided, as shown on the map, p. 310, illustrate other effects of the foldings; for the whole, in all probability, was originally one great area, continuous with that of western Pennsylvania.

Fig. 700.

Section of the Coal measures, half a mile west of Trevorton Gap, Pa.

The sections represented in Figs. 701, 702 illustrate the flexures of the Paleozoic rocks, showing that the whole participated in the system.

Fig. 701.



Section on the Schuylkill, Pa.; P. Pottsville, on the Coal measures.

Fig. 701 (by Lesley) is a section from the Schuylkill, along by Pottsville: the formations included in it embrace from the Potsdam sand-

Fig. 702.

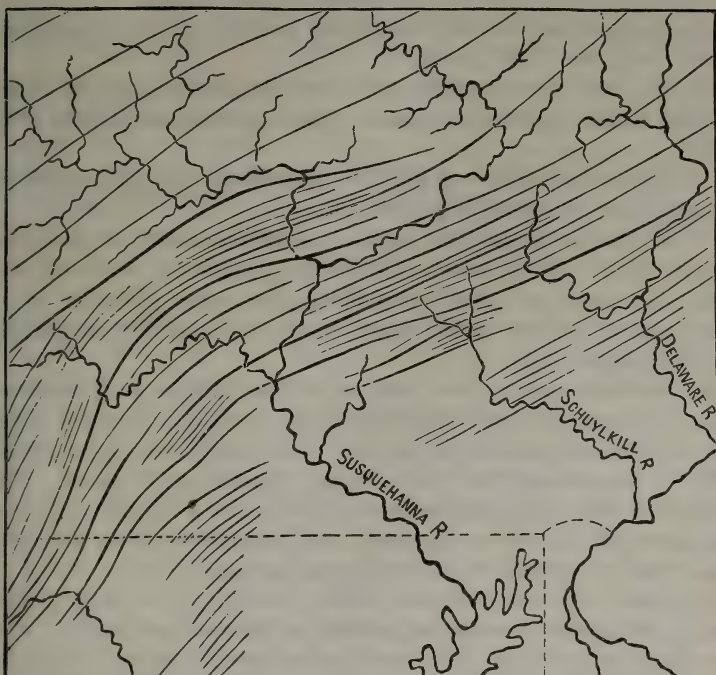
Section from the Great North to the Little North Mountain, through Bon Springs, Va.; *t*, *t*, positions of thermal springs.

stone (2) to the Coal formation (14): the numbers indicate the formations. The section in Fig. 702 (by Rogers) extends from the Great North to the Little North Mountain, through the Bon Springs, in Virginia: it has been partly explained on pages 93, 97. The formations are numbered — II. the Calciferous; III. Trenton; IV. Cincinnati; V. Oneida; VI. Clinton and Lower Helderberg; VII. Oriskany sandstone and Cauda-galli grit.

The mountains of Pennsylvania as well as Virginia are full of such sections. In fact, they present the common features of the Appalachians, from Alabama to New Jersey. It is here obvious that not only the Coal-measures but the whole Paleozoic has been forced by some agency out of its originally horizontal condition into this contorted state. The folds were mountains themselves in extent; but, through the extensive denudation to which they have since been subjected, they have been worn off and variously modified in external shape, until now, as explained on page 96, it is often extremely difficult to trace out the original connections.

The folds are most abrupt to the eastward; to the west, they diminish in boldness, and become gentle undulations; yet there is often a sudden transition to these gentler bendings, along lines of great

Fig. 703.



Map of Pennsylvania, showing the positions of the axes of the folds in the strata.

faults. It would be an error to suppose that the number of folds is uniform, through the length of the Appalachians. On the contrary, all along their course, there are folds rising and others disappearing; they may continue on for a few miles or scores of miles, and some for

much greater distances, and then gradually disappear, while others, more to the east or west, take their places. Thus, in the Appalachian chain, there is a complexity of flexures following a common direction. This character is well shown in Fig. 703, — a map prepared for this work by J. P. Lesley, who, in connection with other assistants in the Geological Survey of Pennsylvania, has done much toward working out the facts here presented. It gives a general view of the direction and number of the folds through Pennsylvania. Each line stands for the axis of a flexure. Without claiming absolute accuracy, it gives a correct general idea of the number and positions of the folds in this part of the Appalachian region.

The following are some of the most important facts established with regard to these Appalachian flexures: —

1. They occupy the whole *Appalachian* and *Eastern-border regions* of the continent, nearly or quite to the Atlantic Ocean.

2. They are parallel with the general course of the mountains, and nearly with the Atlantic coast.

3. They are most crowded and most abrupt over the part of the regions which is toward the ocean, — that is, the southeast side (Fig. 702.

4. The steepest slope of a fold is that which faces the northwest, or away from the ocean (Figs. 701, 702).

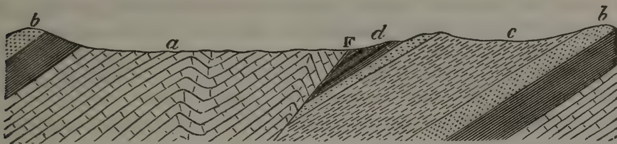
5. They are in numerous ranges; but, while some are of very great length, there is in general a commingling of shorter flexures; and often they are in groups of overlapping lines (Figs. 12 to 17), as explained, with reference to the arrangement of the parts of mountains, on pages 19 and 20.

6. Although many of the folds were like mountains in dimensions, they have been so worn and removed by denuding waters — either those of the ocean, or rivers, or both — that the higher parts of the folds do not generally form the summits of existing elevations. The fissures of the broken mountains would have been deepest and most numerous in the axes of the folds; and hence denudation has been most destructive along the more elevated portions.

2. Faults. — Besides the remarkable plication of the earth's crust in this Appalachian revolution, numberless fractures and faults or dislocations occurred over the whole region, as was natural under the contortions and uplifts in progress. Some of the faultings were of great extent, lifting the rocks on one side of the line of fracture 5,000 or 10,000 feet above the level on the other side. The faults mentioned on p. 214 are of this character; and part of the series there alluded to was probably made at this time. There is one of these great faults west of the eastern range of the Cumberland Mountains,

in eastern Tennessee, well shown in the map and sections of Safford. In southwestern Virginia, there are faults, according to Rogers, of seven or eight thousand feet. One remarkable line of this kind extends along the western margin of the Great Valley of Virginia, throughout the chief part of its length, along by the ridge (on the northwest side of the valley) named, in its different parts, the Little North Mountain, North Mountain, and Brushy Ridge. In some parts, as in the annexed section, Fig. 704 (by Lesley), the Lower Silurian

Fig. 704.



Section of the Paleozoic formations of the Appalachians, in southern Virginia, between Walker's Mountain and the Peak Hills (near Peak Creek Valley): F, fault; *a*, Lower Silurian limestone; *b*, Upper Silurian; *c*, Devonian; *d*, Subcarboniferous, with coal beds.

limestone is brought into conjunction with beds but little below the Subcarboniferous limestone; so that there is a transition from the lower strata to the upper, in simply crossing the fault. In some places, there is an inversion of the strata, so that a bed of semi-bituminous coal of the upper beds is found under the Lower Silurian limestone and conformable to it in dip. This fault continues on for eighty miles. (W. B. & H. D. Rogers.)

Several such examples might be cited from Pennsylvania as well as Virginia. One occurs near Chambersburg, Pa., and is thus described by Lesley in his "Manual of Coal and its Topography" (p. 147). "The western side of the anticlinal 'cove-canoe' has been cut off and carried down at least twenty thousand feet into the abyss, along a fracture twenty miles in length; the eastern side must have stood high enough in the air to make a Hindoo Koosh; and all the materials must have been swept into the Atlantic by the denuding flood. The evidence of this is of the simplest order, and patent to every eye. Portions of the Upper Devonian wall against the lowest portions of the Lower Silurian. The thickness of the rocks between is, of course, the exact measure of the downthrow, which is therefore twenty times as great as the celebrated Pennine Fault in England. Yet a man can stand astride across the crevice, with one foot on Trenton limestone and the other on Hamilton slates, and put his hand upon some great fragments of Shawangunk grit, caught as they were falling down the chasm, held fast in its jaws as it closed, and revealed by the merest accident of lying suspended in the crack just where the plane of denudation happened to cut it."

At the west base of the Chilhowee Mountain, near Montvale Springs, Blount County, Tennessee, Subcarboniferous shales are brought into contact with the "Ocoee" conglomerate of the Acadian epoch, by a fault and displacement of more than 10,000 feet. (Safford.)

Lesley, after explaining the relations of the *eastern* or Blue Ridge, the Great Valley next west, the Appalachian or *middle* chain, and the Alleghany or *western*, and mentioning that the eastern escarpment of the last, "overlooking the Appalachian ranges with their narrow parallel interval-valleys, is the so-called Backbone Alleghany Mountain," and separates the head waters of nearly all the Atlantic and Western rivers, observes that New River, in southern Virginia, divides the northern region of plications from the southern of great faults; and this river is remarkable for cutting through the Appalachians, and taking its rise even as far east as the Blue Ridge. He adds, concerning this southern district, "The Paleozoic zone, included between the Great Valley and the Backbone escarpment, is occupied by as many pairs of parallel mountains as there are great parallel faults; and, as these faults range in straight lines, at nearly equal distances from each other, these mountains run with remarkable uniformity side by side for a hundred or two hundred miles, and are finally cut off, either by short cross-faults, or by slight angular changes in the courses of the great faults." This strip of country is thirty to forty miles wide; and the intervals between the fractures or faults are from five to six miles wide. All the ranges show southeast dips; a portion of the Carboniferous formation forms the southeastern brow of each, overlooking to the southeast Lower Silurian limestone, and resting on Devonian and Silurian, which come into view to the northwest.

According to the Professors Rogers, these faults in southwestern Virginia, which were early described by them, occur along the axes of plications, instead of in monoclinal strata. (Trans. Amer. Assoc. Geol. Nat., p. 494.)

Thus, the whole Continental border, from Alabama to Newfoundland, participated in these grand movements.

3. Alterations of rocks. — The alterations which the rocks underwent at the time of these disturbances are as follow: —

1. *Consolidation.* — Strata were consolidated; for the rocks of the Coal-measures, the conglomerates and sandstones especially, are often very hard and siliceous, where the beds have been most folded or disturbed.

2. *Debituminization of Coal.* — The coal is not bituminous, or is true *anthracite*, where the rocks are most disturbed; and, going westward, into regions of less disturbance, the proportion of bitumen or volatile substances increases quite regularly (Rogers). It appears as if the debituminization of the coal had taken place from some cause connected with the uplifting. In Rhode Island, the effects are still more marked, the coal being altered not simply to an excessively hard anthracite, but in part to graphite.

3. *Crystallization or Metamorphism.* — In some districts, the rocks are changed to gneiss, mica schist, or slates, and granular limestone (marble).

4. Characteristics of the force engaged. — As in the Medio-

Silurian, or Green Mountain, revolution, the cause of the upturning had the following characteristics: —

1. The force acted at right angles to the general direction of the Atlantic coast, the flexures being approximately parallel to the coast-line.

2. It acted from the direction of the ocean, the flexures and metamorphism being greatest on the oceanic side, and fading out toward the interior.

3. It was slow in action and long continued, a result of movement at the rate of a few feet or yards in a century, the flexures having taken place without obliterating, and hardly obscuring, the stratification. There may have been sudden starts, and earthquakes beyond modern experience; but the general course of progress must have been quiet.

4. Heat was concerned in the changes, or produced by the movement; for several thermal springs exist in Virginia, situated, according to Rogers, along the axes of the Appalachian folds, as if some traces of the heat still remained.

5. The force was the same in kind, and also in direction, judging from the identity of results, with that which produced the flexures and other changes that closed Archæan time (p. 155), as well as those of the Medio-Silurian disturbance, and caused the oscillations through the progressing Paleozoic ages required for the completion of the succession of rocks; the same that occasioned the deep subsidences along the Appalachian region. When the Appalachian subsidences were about to cease, then began the new movement that flexed and stiffened the rocks of the Atlantic border.

Although there is no proof, in the flexures or the metamorphism, of any emergence of the strata from the ocean during their progress, there is sure evidence that, when the revolution ceased, it left the Appalachian chain with nearly the present elevation. The evidence of this final result of the moving forces is afforded by the strata of Mesozoic time, which come next under consideration.

In North America, from the close of the Paleozoic, there was a great change in the scene of geological progress, so that the regions are no longer the *Eastern Border*, the *Appalachian*, and the great *Interior Continental;* but, instead, the *Atlantic Border*, the *Gulf Border*, the *Western Interior*, or interior west of the Mississippi, and the *Pacific Border*. The Appalachian region and the eastern part of the Interior basin no longer participate in the rock-making. The new regions coalesce; the third is but a continuation of the Gulf region to the northwest, over the area of the Rocky Mountains, which was still low or submerged, and it is probable that it communicated directly with the Pacific.

2. Disturbances in Foreign Countries.

The disturbances through the course of the Paleozoic ages in Europe appear to have been more numerous and diversified than in America. But they were inferior in extent to those that attended its close. Murchison remarks that the close of the Carboniferous period was specially marked by disturbances and upliftings. He states that it was then "that the coal strata and their antecedent formations were very generally broken up, and thrown, by grand upheavals, into separate basins, which were fractured by numberless powerful dislocations." In the north of England, as first shown by Sedgwick, and also near Bristol, and in the southeastern part of the Coal-measures of South Wales, there is distinct unconformability between the Carboniferous and lowest Permian. Elie de Beaumont has named this system of dislocations *the system of the North of England.* Between Derby and the frontier of Scotland, the mountain-axis is of this date, and trends between north and north-northwest; the region is remarkable for its immense faults. The great dislocations of North Wales may be of the same epoch.

Yet, while it is manifest that the period between the close of the Carboniferous and the beginning of the Triassic was one of enormous disturbances, it is not always clear to what time in this interval particular uplifts should be referred. In the Dudley coal field, the Permian beds, according to Murchison, are conformable to the Carboniferous; but, at the close of the Permian (or at least before the middle of the Trias), there were great dislocations. In other coal regions, as those of France and Belgium, and of Bohemia about Prague, there is other evidence of physical changes, in the absence of Permian beds; while, also, in many places, the beds of the coal regions are much contorted. De Beaumont's *System of the Netherlands* includes dislocations of Permian beds, along the foot of the Hartz Mountains, and in Nassau and Saxony, which preceded the deposition of the Triassic. He distinguishes examples of this system of disturbances in France and some other parts of Europe, and also prominently in South Wales. To his *System of the Rhine*, he refers dislocations and elevations of the Permian sandstone of the Vosges (Grès de Vosges), along the mountains of the Vosges, the Black Forest, and the Odenwald, and shows that they antedate the Triassic period.

In Russia, as well as England, there are tracts where the Permian strata follow on after the Carboniferous without unconformability. It was in this closing part of the Paleozoic era, either after the Carboniferous or after the Permian, that the rocks of the Urals were folded and crystallized; for Carboniferous rocks are flexed and altered in the same manner as in the Alleghany region.

III. MESOZOIC TIME.

The Mesozoic or Mediæval time in the Earth's history comprises a single age only, — the REPTILIAN.

REPTILIAN AGE.

The Age of Reptiles is especially remarkable as the era of the culmination and incipient decline of two great types in the Animal Kingdom, the *Reptilian* and *Molluscan*, and of one in the Vegetable Kingdom, the *Cycadean*. It is also remarkable as the era of *the first Mammals*, — the *first Birds*, — the *first* of the *Common* or *Osseous Fishes*, — and the *first Palms* and *Angiosperms*.

The age is divided into three periods. Beginning with the earliest, they are: 1. The TRIASSIC PERIOD; 2. The JURASSIC PERIOD; 3. The CRETACEOUS or CHALK PERIOD.

These periods are well defined in European Geology. But in North American the separation of the first and second has not yet in all regions been clearly made out.

1. TRIASSIC PERIOD (16).

The name *Triassic*, given to this period, alludes to a threefold division which this formation presents in Germany. This division is local and unessential: it does not occur in other remote parts of Europe, or in England, and is not to be looked for in distant continents.

1. AMERICAN.

The formation in *Eastern* North America, here included, covers part or all of the Jurassic period, and perhaps also the Wealden. It is not supposed to reach back into the Permian, because there are no Paleozoic forms among the plants or animals.

I. Rocks: kinds and distribution.

The rocks are met with in three distinct regions: 1, in the *Atlantic-border region*, between the Appalachians and the coast; 2, in the *Western Interior region*, over part of the slopes of the Rocky Mountains; 3, on the *Pacific Border*.

1. On the *Atlantic Border*, the beds occur in long narrow strips, parallel with the mountains or the coast-line, and occupy valleys that

were formed in the course of the folding of the Appalachians, or earlier. The formation *is made partly Jurassic*, because this appears to be indicated by the fossil plants obtained from some of the beds. They lie unconformably on the folded crystalline rocks, and thus show that they are subsequent to them in age. On the map, page 144, the narrow areas are obliquely lined from the right to the left. The principal of them are: —

(1.) *The Acadian area*, situated along the western margin of the peninsula of Nova Scotia, and about 150 miles long; also in Prince Edward's Island.

(2.) *The Connecticut Valley area*, extending from New Haven on Long Island Sound to Northern Massachusetts, having a length of 110 miles and an average width of twenty miles.

(3.) *The Palisade area*, commencing along the west side of the Hudson River, in the southeast corner of New York, near Piermont, and stretching southwestward through Pennsylvania, as far as Orange County, Virginia, about 350 miles long.

(4.) *The North Carolina area*, commencing near the Virginia line, and extending through North Carolina, over the Deep River region, 120 miles long.

The map of Pennsylvania, on page 310, shows the position of the area in that State, it being distinguished by the same oblique lining as on the general map. It takes the same westward bend with the Appalachians of the State, being parallel with the mountains.

Kinds of rocks. — The rock is in general a red sandstone; often a conglomerate with the stones sometimes one to two feet in diameter, and rarely a black bituminous shale; occasionally impure limestone, or limestone conglomerate. The sandstone is largely a granitic sand-rock made of pulverized granite or gneiss. There are often sudden transitions from sandstone to coarse conglomerate; and, in many places, thin layers of large stones lie in the finer beds. Many layers are obliquely laminated, in a coarse style, showing, like the occurrence of the conglomerate, the action of powerful currents in the deposition of their material; while other portions are thinly laminated, indicating regions of still waters or eddies; and still others are fine, even-grained, brownish-red sand-rock, making an excellent building stone, and often called *freestone* — as at Portland, in Connecticut, and near Newark, in New Jersey. Near Richmond, Va., and along Deep River, N. C., there are valuable beds of bituminous coal. The coarser conglomerates abound on the *western* sides of the areas from New Jersey southward. The Potomac pudding-stone marble of Point of Rocks, Maryland, is of this formation.

Markings on the rocks. — In many regions, the layers of rock are covered with ripple-marks and raindrop-impressions or mud-cracks, — evidences in part of exposure above the water, during the progress of the beds.

In the Connecticut valley, and to a less extent in New Jersey and Pennsylvania, the surfaces of the beds are sometimes marked with the footprints of various animals, as insects, reptiles, and birds; and over 12,000 tracks, averaging 100 tracks for each species of animal, have been taken out.

2. On the *Gulf Border*, there are no Triassic rocks, excepting such as may possibly be buried beneath later formations.

3. The formation supposed to be Triassic, between the Mississippi and the summit of the Rocky Mountains, consists of sandstones and marlytes of usually a brick-red color, and often contains gypsum. It covers a large area between the meridians of 90° and 102° W., including the Indian Territory, parts of Kansas and Northern Texas, and a portion of New Mexico. It outcrops at the base of the eastern ridges of the Rocky Mountains. Over the Rocky Mountain region, west of the eastern Archæan ranges, the Triassic enters largely into the constitution of various mountain ridges, as those of the Elk, Wahsatch, and Uintah ranges. It has great thickness, and is fossiliferous, in Western Nevada. It constitutes a considerable part of the auriferous slates of the Sierra Nevada, affording fossils in some places. It spreads over much of the Colorado Valley, and occurs also near the coast in British Columbia and Alaska.

(*a*.) Areas on the Atlantic Border. — 1. The *Acadian areas.* — (1.) A region in Nova Scotia, forming the east side of the Bay of Fundy, and northeastward in this line, along the northern border of the Basin of Mines. (2.) Prince Edward's Island, covering nearly all of it.

2. The *Connecticut River area.*

3. The *Southbury area.* — A small parallel region in Connecticut, more to the westward, in the towns of Southbury and Woodbury.

4. The *Palisade area.* — This, the longest continuous line, extends from Rockland on the Hudson River, through New Jersey, Pennsylvania, and Virginia, east of the Blue Ridge, being thirty miles wide in some places in New Jersey, twelve on the Susquehanna, and six to eight on the Potomac. It crosses the Delaware between Trenton and Kintnerville, and the Susquehanna at Bainbridge, and ends in Orange County, Va. An area, farther south, in Buckingham County, may be part of it.

5 to 8. *Shorter areas in Virginia*, more to the eastward, and 9, more to the westward. No. 5 lies fifteen miles west of Richmond. No. 6 commences in the same line at Fredericksburg, and extends nearly to Baltimore. No. 7 extends from Chesterfield through Richmond to Petersburg, and appears again in Sussex County. No. 8 is in Prince Edward County. No. 9 extends through Pittsylvania County to Dan River.

9 and 10. *Two North Carolina areas.* — One (No. 10) begins six miles south of Oxford, in Granville County, passes to the westward of Raleigh, crosses Deep River, where it contains coal, and extends six miles into South Carolina: width six to eighteen miles. The second (No. 9) is that of Dan River, and is properly a continuation of the most western Virginia area; it contains the Dan River coal region. The beds of the former have a dip to the southeastward, of the latter, northwestward.

As the several regions are isolated from one another, they naturally differ widely in the succession of beds and in the character of the rocks. They cannot, therefore, be brought into parallelism by reference to mineral characters.

In the Connecticut River region, in Massachusetts, according to Hitchcock, these beds consist, beginning below, of — 1. Thick-bedded sandstone through nearly half the thickness, in some parts a conglomerate. 2. Micaceous sandstone and shale, with fine-grained sandstone. This shale sometimes contains very thin coal seams and fossil fishes. 3. A coarse gray conglomerate, the stones sometimes a foot or more through. Conglomerate beds, equally coarse, occur near New Haven, Conn., with finer beds both to the west and east.

The material has come from the crystalline rocks adjoining, — the granite, gneiss, mica schist, etc., and has not, in general, been much assorted by the action of currents or waves. The thickness has not been satisfactorily ascertained, owing to the extent to which the beds are covered by the stratified Drift and alluvium of the valley, concealing all faults: it cannot be less than 3,000 feet, and may be more than double this.

At Southbury and near Middlefield, Ct., and near Springfield, Mass., there is an impure gray or yellowish limestone, fitted for making hydraulic lime.

In Virginia, the rocks consist, as in New England, of the debris of the older rocks with which they are associated. West of Richmond, where the beds are about 1,800 feet thick, there are 20 to 40 feet of bituminous coal, in three or four seams, alternating with shale. The coal is of good quality, and resembles the bituminous coal of the Carboniferous era. It contains, according to Hubbard, 30 to 35 per cent. of volatile ingredients. On the western side of the Virginia areas is generally a coarse conglomerate, which is often a bowlder deposit. The stones are from rocks to the west, and some from points forty miles or more distant. The longest of these conglomerate beds is that which includes the coarse limestone-breccia called *Potomac marble*, which is well exposed near Point of Rocks, Md. Some of the masses composing it are two feet long. It contains an occasional fragment of Potsdam sandstone (Fontaine).

The North Carolina beds are divided by Emmons into three groups, beginning below: 1. The Lower red sandstone and its underlying conglomerate, estimated at 1,500 to 2,000 feet in thickness. 2. The Coal measures, including shales and drab-colored ripple-marked sandstones, in some places 1,200 feet thick. 3. The Upper red or mottled sandstones and marlytes, separated at times from the bed below by a conglomerate. Of the five seams of coal at the Deep River mines, — the first (or upper) 6½ feet thick, is the best. Emmons obtained 28 to 31 per cent. of volatile ingredients. Good argillaceous iron-ore abounds in the coal region of North Carolina; so that in almost every respect there is a close resemblance to the coal regions of older date.

(*b.*) Western Interior Region. — There is still some doubt as to the age of the beds referred to the Triassic period distributed over the eastern slope of the Rocky Mountains south of the parallel of 38°. They seldom contain fossils; and the few found — occasional pieces of fossil wood — are not sufficient to settle the question. The beds are known to underlie unquestionable Jurassic beds, and hence to occupy a position between the Jurassic and Carboniferous.

(*c.*) Rocky Mountain Region and Pacific Border. — In the Elk Mountains, of the western part of the Colorado Territory, several of whose peaks are over 14,000 feet high, the lower part, for about a thousand feet, consists of Triassic, or Triassic and Jurassic, sandstones and marlytes, nearly horizontally stratified, overlying Carboniferous strata. The high Wahsatch and Uintah Mountains, east of the Great Salt Lake, are also partly Triassic and Jurassic over Carboniferous; in the Wahsatch, the beds consist of sandstones, and are 1,000 to 1,200 feet thick (King). In the West Humboldt range, the Triassic consists of the Koipato group, 4,000 to 5,000 feet thick, and 10,000 feet of "Alpine Trias" (p. 425), containing many characteristic fossils of the genera *Halobia*, *Arcestes*, *Monotis*, etc. (King). The Triassic of the Sierra Nevada is fossiliferous, and has been observed in California, according to Whitney, in El Dorado County, at Spanish Flat, in Plumas County, near Gifford's Ranch, etc.; also in Owen's Valley, along the western flanks of the Inyo and White Mountains.

Rocks of the Upper Colorado, according to Newberry, lie between the Carboniferous and the Cretaceous; and the whole thickness is 2,000 to 2,500 feet. But it is not yet known whether all these beds are of the Triassic, or whether they cover both the Triassic and Jurassic periods.

The Triassic has been identified by fossils also in British Columbia (?), and near the entrance of Pavalouk Bay, etc., in Alaska (Am. J. Sci., III. v. 473); also near Sonora, Mexico. Whitney states that the Triassic of California and also that of Alaska is *Upper* Triassic, or the equivalent of the St. Cassian beds of Central Europe, which is that of the Middle Keuper.

II. Life.

The American Triassic formation of the *Atlantic Border* is remarkable for the paucity of all evidences of distinctively marine life.

The same is true of the Triassic rocks of the *Western Interior*. But the beds of the Pacific slope, in the Humboldt Mountains and northern California and Mexico, contain many marine fossils.

Figs. 705–709.

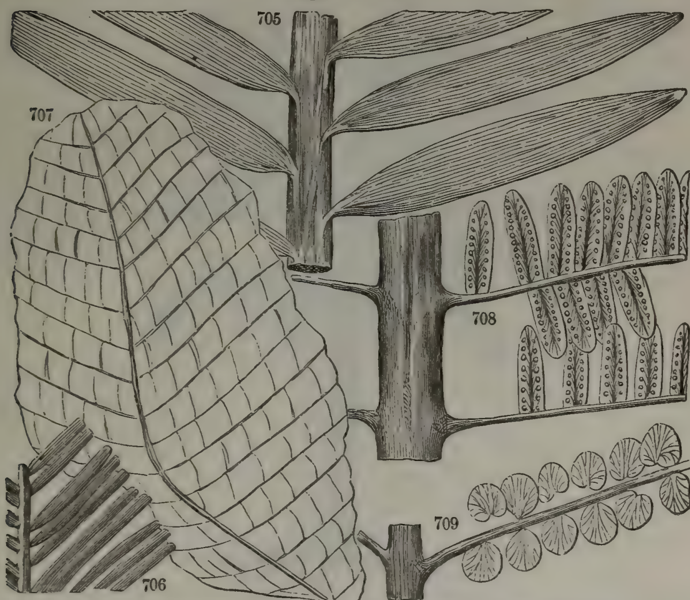


Fig. 705, Podozamites lanceolatus; 706, Pterophyllum graminioides; 707, Clathropteris rectiuscula; 708, Pecopteris bullata?; 709, Cyclopteris linnæifolia.

On the Atlantic Border, extensive coast-accumulations may have been formed, containing marine fossils, as on the Pacific side and in Europe; but none such are now exposed to view.

1. *Plants.*

The vegetation of the Triassic period included neither *Sigillarids* nor *Lepidodendrids*, characteristic groups of the Carboniferous era;

but, instead, there were *Cycads*, along with many new forms of Ferns, Equiseta, and Conifers. Figures 705 to 709 show this contrast between the floras of the Carboniferous and Triassic eras. Figs. 705 and 706 represent the remains of leaves of some of the Cycads; Figs. 737 and 738, a foreign species of one of the Conifers, a *Voltzia* related to the Cypress; and Figs. 707, 708, and 709 are species of ferns. Trunks of Conifers occur occasionally in the sandstone. One, found near Bristol, Conn., was over fifteen feet long and a foot in diameter. No species of grass or moss have been met with. The remains of plants are sufficient to show that the forest vegetation consisted mainly of *Conifers, Tree-ferns, and Cycads.* As the Cycads were the most characteristic trees of the early and middle Mesozoic, a figure of a

Fig. 710.

Cycas circinalis ($\times \frac{1}{120}$).

common species, of the Moluccas (where it grows to a height of thirty or forty feet), is here annexed. (1.) The habit is that of a Palm. (2.) The manner in which the leaves are developed is like that of most Ferns, they coming forth coiled up, and uncoiling as they expand. But, while thus comprising some fern-like and palm-like characteristics, (3.) the Cycads are fundamentally, that is in their fruit and wood, true Gymnosperms, or related to the Pine tribe. The wood has a

very large pith, abounding in starch, surrounded by one or more rings of wood, each the result of several years growth.

Characteristic Species.

Conifers. — The genus *Voltzia* contained cypress-like trees, having lax leaves, the terminal often longer than the others; and the fruit-branchlet consisted of broad and short leaves or scales. A species near *V. heterophylla* Schimp. (Fig. 737) has been found in the American rocks, at the Little Falls of the Passaic, in New Jersey. Several Fir cones, six inches long, have been found at Phœnixville, Pa.; and a small one from the Massachusetts beds has been figured by Hitchcock.

Cycads. — *Pterophyllum longifolium* Braun, from North Carolina and Pennsylvania, characteristic of the Upper Trias in Europe, resembles much Fig. 739; *P. graminioides* Emmons, Fig. 706, from North Carolina. Fig. 705, *Podozamites lanceolatus* Emmons, from the same locality.

Acrogens. — Fig. 707, *Clathropteris rectiuscula* Hk., from Easthampton, Mass., near the middle of the Sandstone formation: in one specimen there were seventeen such fronds radiating from one stem. Fig. 708, *Pecopteris bullata?* (Fontaine), from the Richmond Coal-beds. Fig. 709, *Neuropteris linnæifolia* Bunbury, from Richmond; *Macrotæniopteris grandifolia*, abundant, ibid. Other ferns are the *Acrostichites oblongus* Göpp., and *Laccopteris falcata* Emmons, both from North Carolina. *Equisetum Rogersii* Schimp, occurs at Richmond, Va., and in Pennsylvania. One or two *Calamites* have been found in North Carolina.

The vegetation of the Richmond beds is, according to Rogers (and also Fontaine), more Jurassic than Triassic; while that of the more eastern Petersburg area is referred by Fontaine to the Wealden. These include Conifers near *Araucarites curvifolius* Ett., and the Cycad *Pterophyllum Buchianum* Ett., in great abundance, both Wealden species in Europe. *Pterophyllum longifolium* is Upper Triassic in Europe; *Neuropteris linnæifolia* is near *N. pachyrachis* Schimp., also Upper Triassic; *Clathropteris* and *Voltzia* are Triassic or Jurassic. The prevalence of Cycads is decidedly Mesozoic, and not Permian.

2. *Animals.*

On the Atlantic Border, the Triassic rocks have afforded no traces of *Radiates*, and but few of *Mollusks.* This singular fact is partly accounted for through another, already stated, — that the beds are either fresh-water or brackish-water deposits.

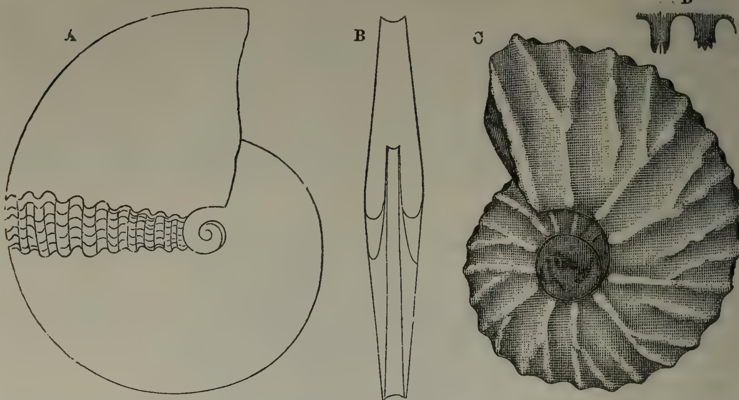
On the Pacific Border, in California and Nevada, the beds have afforded many marine fossils. Among them are species of the Paleozoic genera *Spirifer*, *Orthoceras*, and *Goniatites;* besides others that are as strikingly Mesozoic, such as Lamellibranchs of the genera *Monotis*, *Myophoria*, etc., and Ammonites of the genus *Ceratites*, etc. (Figs. 710 A–D), and others.

A foreign species of Triassic *Myophoria* is represented on page 426.

The Devonian *Goniatites* were the earliest known representatives of the Ammonite group of Cephalopods, the prominent characteristics of the shells of which are that the siphuncle is dorsal, and the transverse partitions are flexed at the margin so as to make there a series of pocket-shaped cavities opening upward. Figs. 710 A, B are dif-

ferent views, in profile, of a species of *Ceratites*, one of the genera of the Ammonite group; and 710 C a second species, reduced in size one third. The partitions are not seen over the exterior of the shell, and hence nothing of them is shown in Fig. 710 C. In 710 A, a few

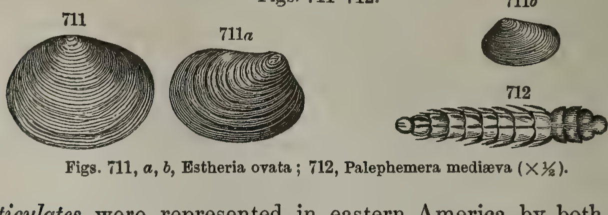
Fig. 710 A, B, C, D.



AMMONITE FAMILY. — Fig. 710 A, Ceratites Haidingeri; B, same in profile; C, Ceratites Whitneyi D, same showing form of pockets.

are represented, to exhibit their character. Each downward flexure corresponds to a depression or pocket-like cavity; and, as in other species of *Ceratites*, these pockets are quite simple in form, and numerous. Fig. 710 D represents two of the pockets of 710 C. Fig. 744, p. 426, represents a foreign *Ceratites*; and Fig. 746, another of the Ammonite group, in which the openings of the pockets around the margin of the outer chamber of the shell are shown. The mantle of the living Cephalopod (whose body filled the outer chamber) descended into the pockets, and thus aided the animal in holding to its shell. Fig. 845, p. 463, represents another species of the Ammonite group, of later age, which has the pockets very complex, as seen in Fig. 845*b*. showing the outline of several of them.

Figs. 711–712.



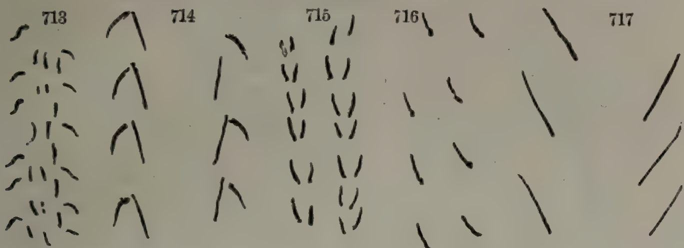
Figs. 711, *a*, *b*, Estheria ovata; 712, Palephemera mediæva (×½).

Articulates were represented in eastern America by both Crustaceans and Insects. The Crustacean remains are, with a single excep-

tion, Ostracoids; and some of the species occurred in great numbers. Three varieties of them are represented in Figs. 711, *a*, *b*. The only fossil Insect observed is the larve (or exuvia of the larve) of a *Neuropter* (Fig. 712) related to the genus *Ephemera*, from Turner's Falls, on the Connecticut; it is about three-quarters of an inch long.

But, although relics of Insects and of Crustaceans other than Ostracoids were rare, several species of these classes of Invertebrates, and also of Worms, are indicated by the tracks which they left on the fine mud, that is now shale. Figs. 713–717 represent some of these foot-

Figs. 713–717.



Figs. 713-715, Tracks of Insects; 716, 717, Tracks of Crustaceans (?).

marks. Those of Insects were probably made by larves which lived in water, like those of many Neuropters. Nearly thirty species of Articulates have been named by Hitchcock from the tracks.

The *Vertebrates* thus far made known, by their fossils and footprints, outnumber all other known kinds of animal life; and many were of remarkable size. They included not only *Fishes* and *Reptiles*, but also the first of *Mammals*, and probably also the first of *Birds*. Thus the sub-kingdom of Vertebrates had, from this earliest period of the Mesozoic, all its grander subdivisions or classes represented.

The *Fishes* were all Ganoids (Fig. 718). Unlike the Paleozoic,

Fig. 718.

Fig. 718, Ganoid, Catopterus gracilis (×½); *a*, Scale of same, natural size.

they include, along with species having *vertebrated* tails, others that have the tails only *half-vertebrated*, or *not vertebrated* at all; and this

is the last period in which this old Paleozoic characteristic appeared. Thus, as Agassiz first observed, the progress of the ages was marked in the tails of the fishes.

Amphibians and *True Reptiles* were very numerous, and various in size. But, although fragments of the skeletons of several species have been found, most of the species are known only from their foot-

Figs. 719–724.

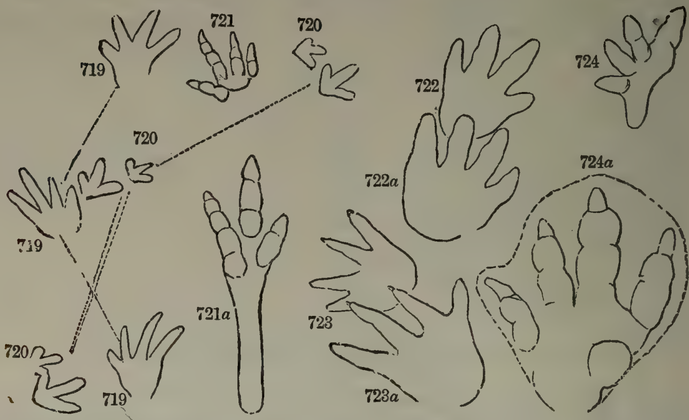


Fig. 719, Macropterna divaricans (×1/6); 720, Apatichnus bellus (×1/2); 721, Anomœpus scambus, fore-foot (×1/6); 721 *a*, hind foot of same; 722, Anisopus Deweyanus, fore foot (×1/2); 722 *a*, hind foot of same; 723, A. gracilis, fore foot (×2/3); 723 *a*, hind foot of same; 724, Otozoum Moodii, fore foot; 724 *a*, hind foot of same (both ×1/18).

prints, Figs. 719–730. Their fossil bones have been discovered in Prince Edward's Island, Massachusetts, Connecticut, Pennsylvania, and North Carolina. One of the most interesting localities is at Phœnixville, Pa., where there is literally "a bone-bed," as described by Wheatley. The footprints, like those referred to birds, are most numerous in the Connecticut valley area.

1. Amphibians, of the order of *Labyrinthodonts,* whose tracks are four-toed or five-toed and often hand-shaped. The ordinary Labyrinthodonts were *quadruped-like* in locomotion, the fore-feet being ordinarily used in walking as well as the hind feet. Fig. 722 represents the track of the fore-foot of one of the species, and 722 *a*, that of the hind foot, both half the natural size; and Figs. 723, 723 *a*, are the tracks of the fore and hind feet of another species, two thirds the natural size. Several other kinds are figured by Hitchcock in his memoir on the Footprints (Ichnology) of New England.

2. True Reptiles existed of the following kinds: —

1. *Dinosaurs.* — The Dinosaurs were to a large extent biped in locomotion, like birds, seldom bringing their fore-feet to the ground.

There were two groups: *one*, in which the hind feet were *three-toed*, and undistinguishable in the tracks they made from those of birds; and a *second*, in which the hind feet were *four-toed* or *five-toed*, and much resembled those of the Labyrinthodonts. In each, the *fore-feet* were four-toed or five-toed, as is known from the occurrence occasionally of impressions of these feet along with those of the hind-feet, and also from skeletons of related species found in the Jurassic and Cretaceous rocks of the West.

The *Three-toed Dinosaurs* were numerous, and some were of gigantic size. The tracks were at first referred to birds, but the most of them have been proved to be tracks of Dinosaurs by the occurrence of impressions of the fore-feet on some slabs. Fig. 721 *a* represents the track of the hind-foot of one of the species of the Connecticut Valley, and 721 that of the fore-foot. Fig. 725 shows the form of the largest of the three-toed tracks, its length in some specimens being nearly two feet. It is the *Brontozoum giganteum* of Hitchcock. The depth of the track, and the great length of the stride, prove that it was both tall and heavy; fourteen feet has been estimated for the height, but this is a minimum.

Fig. 725.

Brontozoum giganteum (× $\frac{1}{6}$).

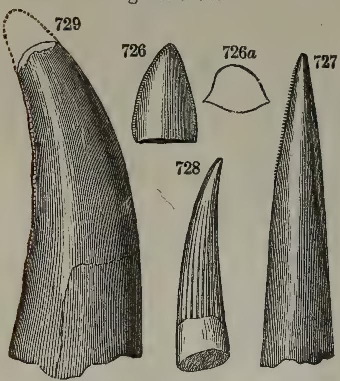
The *four-toed* or *five-toed Dinosaurs* of the era, were of as gigantic forms as the three-toed, and probably much exceeded them in the magnitude of some species. They were as completely bipeds as the preceding. Fig. 724 *a* gives the form of one of the hind-foot tracks, the actual length of which was *twenty inches;* the stride was three feet. Eleven consecutive tracks have been observed on a single surface of sandstone. The form of the fore feet, which were sometimes brought to the ground, is shown in Fig. 724. The species is called by Hitchcock *Otozoum Moodii.* No impression of a tail has been observed on any of the slabs, and hence this part must have been short. Three consecutive hind-foot tracks of a smaller species is represented in Fig. 719; the tracks were about three inches long. In one of these biped species the tracks are but a fourth of an inch long.

The idea that the four-toed bipeds were Amphibians was set aside by Professor Marsh after the discovery of large four-toed Dinosaurs, as well as three-toed, in the Jurassic

beds of Colorado and Wyoming. Figures of the limbs of the two kinds are given, from Marsh, on Plates I., II., III. The biped or more bird-like Dinosaurs resembled birds in having the feet very similar in the phalanges; the long bones of the leg generally hollow; the pelvis bird-like in many of its details, as seen on comparing Fig. 4, Plate III., with Fig. 7, Plate IV. The Morosaurus (Plate I.) and related species (p. 433) used all fours in locomotion, and were far from bird-like in structure; yet it was probably able to raise itself on its hind legs against a tree for browsing, though not to perfect erectness.

The bones of a Dinosaur, "as large as a hound," were found near Springfield, Mass., and named, by Hitchcock, *Megadactylus.* (This name having been before used, Marsh has substituted *Amphisaurus.*) Its leg bones were slender and hollow, like those of birds, and the walls thin and dense. Portions of the skeleton of a related species were found in the red sandstone near Windsor, Connecticut. The tooth of another species called *Clepsysaurus*, found both in Pennsylvania and North Carolina, is represented in Fig. 727. A skull, with teeth *four inches* long (Fig. 729), from Prince Edward's Island, has been called *Bathygnathus* by Leidy.

Figs. 726–729.



Figs. 726, 726 *a*, Belodon priscus ; 727, Clepsysaurus Pennsylvanicus; 728, Belodon Carolinensis ; 729, Bathygnathus borealis (× ⅙).

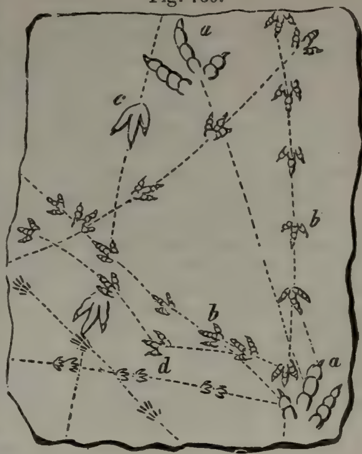
Crocodilians. — Figs. 726, 728, represent teeth referred to species of the Triassic genus *Belodon.* Fig. 726 repre ents one of the posterior teeth of *B. priscus*, and 728, one of the anterior of *B. Carolinensis*, both from the coal-bearing Triassic beds of North Carolina. Another, described by Cope, *B. lepturus*, from the Phenixville bone bed, Pennsylvania, had, according to the describer, a length of about ten feet, and a habit stouter than that of the Crocodiles of the present day. The teeth, in the Belodons, were in sockets, and hence the name *Thecodonts* applied to the group, derived from the Greek θήκη, *case*, and ὀδούς, *tooth.* While Crocodilians, these saurians had some of the characteristics of the Lizards. The foreign species come from the Upper Trias of Germany.

Bones, found at Phœnixville, Pa., that were formerly referred to a *Pterosaur* or flying lizard, have since been supposed by Cope to belong to a *Rhynchosaur ;* but their true nature is still in doubt.

Enaliosaurs or Swimming Saurians. — Leidy has described a species of *Enaliosaur* (or *Sea-saurian*, as the word signifies), from the Triassic rocks of Humboldt County, Nevada.

Birds. — The evidence with regard to the existence of *Birds* at this period has been shaken by the discovery of the three-toed reptile-tracks; and it is very probable, as was early suspected, that all the supposed bird-tracks will turn out to be Reptilian. Still, it is possible that there were Birds as well as Reptiles, for the existence of birds in the Jurassic era in Europe has been proved by the discovery of specimens (p. 447).

Fig. 730.



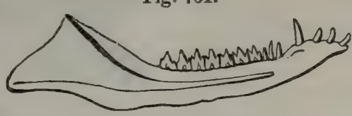
Slab of sandstone, with tracks of Birds (?) and Reptiles ($\times\frac{1}{30}$).

The tracks referred to Birds, are very various in kind and size. Fig. 730 (from Hitchcock), represents a large slab, with its lines of tracks, showing that a number of these three-toed animals (*a*, *b*, *c*) and at least one Amphibian (*d*) passed over the muddy surface during the same day, or before the tides or freshets made new depositions of detritus: the tracks, *a*, *a*, are enlarged views of *b*, and still are only one tenth of the natural size. Three-toed tracks not yet proved by impressions of fore-feet to be those of Reptiles, have been found not only at various places in the Connecticut valley, but also in New Jersey above Trenton, and in Pennsylvania near Easton, and at the Phœnixville tunnel on the Schuylkill.

Of all the various kinds of tracks found in the Connecticut valley, the collections of Amherst College, made chiefly by Professor Edward Hitchcock, and also that of Yale College, contain each several thousands of specimens; a fact that gives some idea of the abundance of life on the continent in Triassic time. Other estuaries and valleys besides those now occupied by Triassic beds, were probably equally populous. Twenty-one consecutive tracks of the Otozoum were exposed to view in 1874, at one of the Portland quarries.

Mammals. — The only *Mammal* thus far discovered in the American rocks was made known by Professor Emmons. The specimens are two jaw-bones (Fig. 731), found in North Carolina. According to Professor Owen, they belonged to an Insectivorous (insect-eating)

Fig. 731.



Dromatherium sylvestre.

Marsupial[1] near the modern genus *Myrmecobius* of Australia.[2] The species has been named, by its discoverer, *Dromatherium sylvestre*. Mammals of similar kinds probably spread over the continent, and may have been of many species.

Characteristic Species.

1. Mollusks. — *Lamellibranchs.* — *Myacites Pennsylvanicus* Conrad, from the black slate of Phœnixville, Pa. Two other species occur at the same locality.

In California or Nevada, are *Orthoceras Blakei* Gabb, *Goniatites* (*Ammonites*) *levidorsatus* Hauer, *Ceratites* (*Goniatites*) *Haidingeri* Hauer, *C. Whitneyi* Gabb, *Ammonites Blakei* Gabb, *A. Ausseanus* Hauer, *A. Billingsianus* Gabb, *Halobia dubia* (?) Gabb, *Monotis subcircularis* Gabb, *Posidonomya stella* Gabb, *Myophoria alta* Gabb, *Spirifer Homfrayi* Gabb, besides other species.

2. Articulates. — (*a.*) *Crustaceans.* — Ostracoids: Fig. 711, *Estheria ovata* Lea (*Posidonia minuta*), from Richmond, Va., and Phœnixville, Pa., resembles the *P. minuta* of the European Trias; Fig. 711 *a*, *E. ovalis* Emmons, from North Carolina, and Fig. 711 *b*, *E. parva* Lea, Phœnixville, Pa., are both *E. ovata*, according to T. R. Jones. Two species of *Cypris*, one smooth, and the other granulate, occur at Phœnixville and Gwynned, Pa. Figs. 716, 717 represent tracks referred by Hitchcock to Macrouran Crustaceans.

(*b.*) *Insects.* — Fig. 712, exuvia of a Neuropterous larve, related to *Ephemera*, according to J. L. Le Conte: the appendages along the sides are probably branchiæ attached to the abdomen. Tracks of different insects are shown in Figs. 713–715, from Hitchcock. On comparing especially Figs. 713, 714 with the footprints of some living Insects, Dr. Deane found a close resemblance between them.

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[1] *Mammals.* — The highest group of Vertebrates are of two grand divisions: —

I. The *Ordinary or True Viviparous Mammals*, such as the Monkey, Lion, Elephant, Ox, Bat, Mouse, Whale, etc.

II. The *Semi-oviparous Mammals*, which are, with one exception, *Marsupial.* — Birth takes place before the ordinary degree of maturity in the embryo is attained, and they thus approximate to oviparous vertebrates. The immature young in these Marsupials are passed into a pouch (*marsupium*), situated over the venter of the mother, in which they are nourished from her teats, until the degree of maturity required for independent existence is attained. They are the lowest, and geologically the earliest, of Mammals.

[2] A view of the *Myrmecobius* is here given.

Fig. 732.

732, Myrmecobius fasciatus (×¼).

3. Vertebrates. — (*a.*) *Fishes.* — Fig. 718, *Catopterus gracilis* Redfield (reduced one half), from Middlefield, Ct.; also found in North Carolina and at Phœnixville, Pa.; 718 *a*, scale of same, natural size. There are also other species of *Catopterus;* also species of *Ischypterus* and of *Turseodus* Leidy (related to *Belonostomus* or *Eugnathus*). In the last, the tail is not at all vertebrated. *Radiolepis speciosus* Emmons is another Ganoid, from North Carolina and Pennsylvania.

The best localities of fossil fishes are Sunderland, Mass.; Middlefield Falls and Southbury, Ct.; Richmond Coal-beds, Va.; Phœnixville, Pa.

Amphibians. — Fig. 723, *Anisopus gracilis* Hk., reduced one third. Fig. 722, *Anisopus Deweyanus* Hk., half natural size. Fig. 719, *Macropterna divaricans* Hk. (reduced to one sixth). Portions of the skeleton of Amphibians have been detected by Leidy among the fossils of Gwynned, Pa., twenty miles north of Philadelphia, and also among those found at Phœnixville; and Emmons has figured a portion of the head of a fine species from North Carolina.

(*c.*) *Dinosaurs.* — Figs. 721, 721 *a*, tracks of fore and hind feet of *Anomœpus scambus* Hk.; 729, tooth, reduced one-half, of *Bathygnathus borealis* Leidy, from a jaw found in the rocks of Prince Edward's Island, referred to the Amphibians by Leidy, to the Thecodonts by Owen, and to the Dinosaurs by Cope. Fig. 724, *Otozoum Moodii* Hk., one eighteenth natural size. Fig. 727, tooth, natural size, of the *Clepsysaurus Pennsylvanicus* Lea, the edge sharp-denticulate, from North Carolina, and Phœnixville, Pa.

(*d.*) *Crocodilians.* — 726, one of the back set of teeth of *Belodon priscus* Leidy, from North Carolina; 726 *a*, section of same; 728, one of the front set of teeth of *B. Carolinensis* Cope, from North Carolina, and Phœnixville, Pa.; *B. Leaii* Cope, from North Carolina; *B. lepturus* Cope, from Phœnixville. Also the Rhynchosaur (according to Cope), *Rhabdopelix longispinis* Cope, from Phœnixville, formerly regarded as a Pterosaur.

Coprolites are abundant in the shales of Phœnixville.

(*e.*) *Birds* (?). — Fig. 725, *Brontozoum giganteum* Hk., reduced to one-sixth natural size. Fig. 730, part of a slab of sandstone figured by Hitchcock, one-thirtieth natural size: *a*, *b*, *c*, three kinds of bird-like tracks; *a* and *c*, of the genus *Brontozoum* Hk.; *a*, *a*, same as *b*, but drawn larger, to show the articulations of the toes. Figs. *d*, *e*, two kinds of Reptilian tracks, of the genus *Anisopus* Hk., *d*, *Anisopus Deweyanus* Hk. Natural length of *a*, 4 inches; of *b*, 8 to 9 inches; of *c*, $3\frac{3}{4}$ inches; of *d* and *e*, 1 to $1\frac{1}{2}$ inches. The best localities of tracks of birds and other animals are at Greenfield and Turner's Falls, Mass.; Portland, Conn.

(*f.*) *Mammals.* — Fig. 731, *Dromatherium sylvestre* Emmons, from North Carolina. Owen says of the species that "this Triassic or Liassic Mammal would appear to find its nearest living analogue in *Myrmecobius*, Fig. 732, p. 416; for each ramus of the lower jaw contained ten small molars in a continuous series, one canine and three conical incisors, — the latter being divided by short intervals."

III. Disturbances. — Igneous action. — Trap rocks.

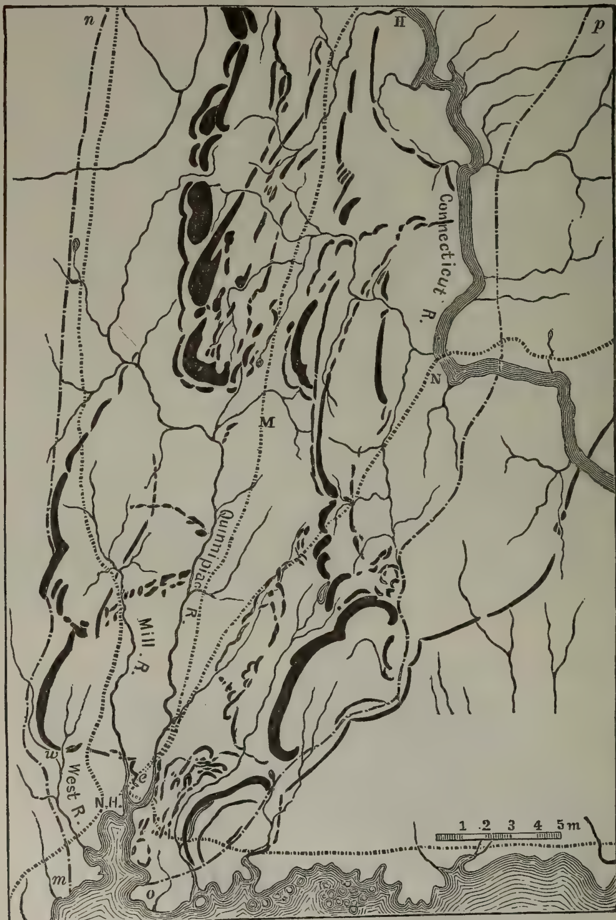
Trap ridges and dikes accompany this formation on the Atlantic border. The rocks constituting them are of igneous origin, and were ejected in a melted state, through fissures in the earth's crust. It is remarkable that these fractures should have taken place in great numbers just where the Triassic beds exist, and only sparingly east or west of them; and also that the igneous rock should be essentially the same throughout the thousand miles from Nova Scotia to North Carolina. The igneous and aqueous rocks are so associated that they necessarily come into the same history. Mount Tom and Mount Holyoke, of Massachusetts, are examples of these trap ridges; also East Rock and

West Rock, near New Haven, and the Hanging Hills, near Meriden, in Connecticut; the Palisades along the Hudson, in New York; Bergen Hill and other elevations in New Jersey.

In Nova Scotia, trap ridges skirt the whole red sandstone region, and face directly the Bay of Fundy; Cape Blomidon, noted for its zeolitic minerals, lies at its northern extremity, on the Bay of Mines.

In Connecticut, the ridges and dikes are exceeding numerous, showing a vast amount of igneous action. The following map (Fig. 733),

Fig. 733.



Map of part of the region in central Connecticut, from New Haven, northward. The lines *mn*, *op* show the outlines of the Triassic area; N. H., New Haven; N., Middletown; H., Hartford; M., Meriden, west of which are the "Hanging Hills;" *w.*, West Rock; *e.*, East Rock.

from a more complete one of the State, by Percival, gives some idea of their number and position. They commence near Long Island Sound, at New Haven, where they form some bold eminences, and extend through the State, and nearly to the northern boundary of Massachusetts. Mounts Holyoke and Tom are in the system. The general course is parallel with that of the Green Mountains.

Although the greater part of the dikes are confined to the sandstone regions, there are a few lines outside, intersecting the crystalline rocks, and following the same direction; and part, at least, of these belong to the same system.

Even the little Southbury Triassic region, lying isolated in western Connecticut, has a large number of trap ridges, and such a group of them as occurs nowhere else in New England, outside of the Triassic. Their direction and positions in overlapping series are the same as in the Connecticut valley.

The trap usually forms hills with a bold columnar front and sloping back; when nearly north and south in direction, the bold front is to the westward in the Connecticut valley, and to the eastward in New Jersey. It has come up through fissures in the sandstone, which varied from a few inches to 300 feet or more in breadth. In many cases, it has made its way out by opening the layers of sandstone; and in such cases it stands with a bold front, facing in the direction toward which it thus ascended.

The proofs that the trap was actually melted are abundant. For the sandstone rocks have in many places been baked to a hard grit by the heat, and at times so blown up by steam as to look scoriaceous; and such layers have been actually taken in some cases for beds of scoria. In some places, the uplift has opened spaces between the layers, where steam has escaped and changed a fine-grained clayey sandstone into a very hard rock looking like trap. Occasionally, crystalline minerals, as epidote, tourmaline, specular iron (hematite), garnet, and chlorite, are among the results of the heat or hot vapors. The evidences of heat, moreover, diminish as we recede from the ridges. There is no doubt that the sandstone in many places owes its escape from denudation to the firm consolidation it derived from the heat and vapors rising with the eruptions, and to the waters of hot springs then set in action.

In all the several regions along the Atlantic border, the sandstone strata are in most parts much tilted. In North Carolina, there is generally a dip of 10° to 22° to the southeast (Emmons); in Virginia, Maryland, Pennsylvania, and New Jersey, the dip is to the northwest or north-northwest (Rogers); in Connecticut and Massachusetts, to the east or southeast, the amount seldom exceeding 23°.

Some of the dikes of trap and fissures in the sandstone, in Con-

necticut and New Jersey, contain copper-ore (copper-glance, erubescite and malachite); and there is little doubt that the copper veins and the barite (sulphate of barium), which is often the gangue of the vein, originated in the same period of eruption. The red color of the sandstone — a consequence of the oxydation of iron present in it — appears to have had its origin in the same cause.

This history of the Triassic of the Atlantic border and its trap dikes appears to be a repetition of what took place long before, during both the Huronian and the Lower Silurian eras, in the Lake Superior region, where a similar subsidence (at least 10,000 feet in the former, and 3,000 or 4,000 in the latter) and similar igneous eruptions accompanied the formation of the beds.

IV. General Observations.

General Progress. — The following points bear upon the history of this period in Eastern North America: —

I. *The position of the rocks in linear ranges, parallel with the mountains, and therefore along depressions in the surface that existed when the period opened.* — The Connecticut valley is one of the great depressions. Such areas would naturally have become inlets of the sea, or estuaries, river-courses, lakes, or marshes, and would have received the debris of the hills brought in by streams.

II. *The absence of Radiates, the paucity of Mollusks, and the presence of few species that are properly marine.* — These facts prove that the ocean had imperfect access, where any, to the regions; that the beds were therefore estuary or lacustrine, and not sea-shore formations like the Cretaceous and Tertiary of later times. The occurrence of vegetable remains and of the coal beds sustains this conclusion.

III. *The mud-cracks, raindrop-impressions and footprints.* — These show, wherever they occur, that the layer was for the time a half-emerged mud-flat or sand-flat; and, as they extend through much of the rock, there is evidence that the layers in general were not formed in deep water. They abound especially in the upper half of the Connecticut-valley strata.

IV. The occurrence, in some parts of the Connecticut valley, of coarse conglomerate, some of the stones of which are very large, and of a coarse kind of oblique lamination in much of the rock, is evidence that some of the beds were deposited by a flood of waters pouring violently down this valley; and they seem also to indicate that floating ice must have been concerned in part of the deposition. The granitic and unassorted character of the sands looks as if the material had been made by the disintegration of New England rocks, through a

long era, and finally, in the Triassic era, had been swept off from the land into the valley, by the flood referred to.

V. *The thickness,* — 3,000 *to* 5,000 *feet or more.* — We learn from this thickness, in connection with the fact just stated, that the areas underwent a gradual subsidence of 3,000 to 5,000 feet or more; consequently, that these oblong depressions made at the time of the foldings were slowly deepening, and continued to deepen until the last layer was laid down.

VI. *The tilted condition of the beds, without evidence of folds.* — The tilting must be a result of mechanical force; and, as the bedding is well preserved, while joints are common, it follows that the force was very gradual in its action. Under V., a profound subsidence is stated to have been in progress, in the regions of depression occupied by the strata. Such a subsidence would have brought a strain upon the rocks of the trough below, and sooner or later would have produced fractures and disturbance; and, if one side or part of the depression were undergoing more subsidence than the opposite, it would have caused that oblique pushing of the beds that would have ended in faulting and tilting them. The direction of the dip and strike, in such a case, would depend on the relative positions, with reference to the whole basin, of the parts undergoing greatest and least subsidence.

VII. *The sandstone strata intersected by dikes of trap.* — These dikes are proofs that fractures took place. The subsidence of such a region would have brought increasing tension or strain upon the rocks below, tending to produce fractures, especially about the axial region of the depression. Either thus, or as a direct result of the lateral pressure, openings were made for the escape of the melted rocks. See, further, pp. 801, 803.

The manner in which the trap at its eruption has sometimes separated the layers of sandstone, and in this way escaped to the surface, instead of coming up through the fissures simply, shows that the rock had been tilted extensively before the ejection.

In the north-and-south ridges of the Connecticut valley, the trap which thus escaped now shows, as already observed, a bold front *to the westward,* the dip of the sandstone being to the eastward. Now, in this bold columnar front, the angle of inclination in the columns is just the angle of dip in the sandstone, the columns being at right angles to the layers of sandstone. Hence, the inclination in the sandstone layers existed before the time of ejection, and determined the position of the columns; for the columnar structure of trap is always at right angles to the cooling surfaces; and these surfaces were those of the opened layers of sandstone. We have proof therefore that there was a tilting of the strata in progress, before the final breaking and ejections.

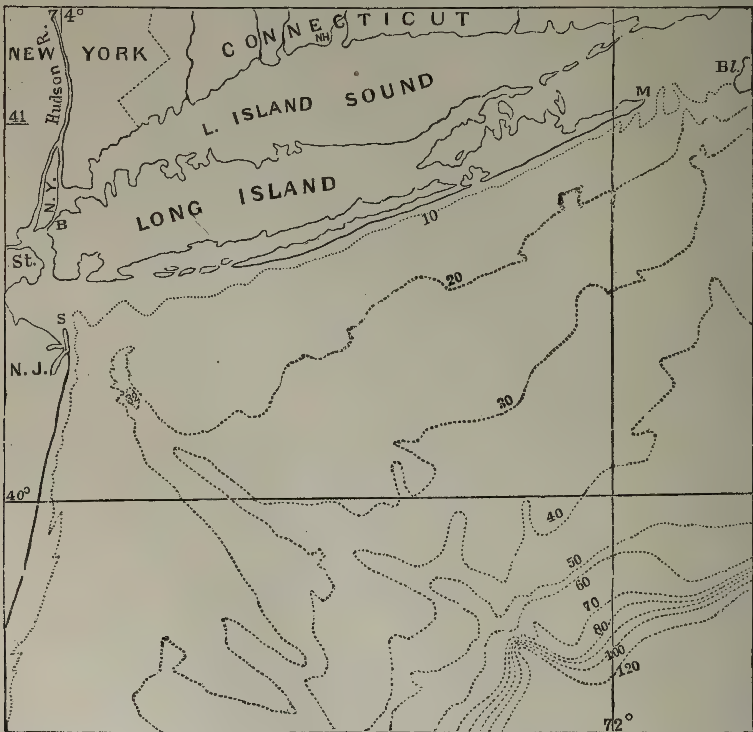
Era of the Eruptions of trap. — As the trap dikes intersect the *later* beds of the formation, the igneous ejections must either have been among the closing events of the sandstone period, or have occurred in a succeeding epoch.

Thus the period of these rocks came to a close somewhat similar to

that of the Carboniferous age. The Carboniferous age ended in a period of disturbance, escape of heat, as shown in consolidations and metamorphism, and a general destruction of life along the Continental border; and so the period of these sandstones was closed in uplifts, fractures, emissions of heat, consolidations, and destructions of life. But, in the former case, the catastrophe resulted in mountain-making through foldings; in the latter, the action, though ranging along the same line of coast, from South Carolina to Newfoundland, was more limited; the surface rocks were only tilted and broken, and heat exhibited its effects chiefly in eruptions of melted rock.

Geography. — The position of the beds on the Atlantic border shows that this part of the continent stood nearly at its present level. The

Fig. 735.



Map of the submerged border of the continent, off New Jersey and Long Island, with lines of equal soundings in fathoms. N. Y., City of New York; N. J., State of New Jersey; N. H., New Haven; B., Brooklyn; St., Staten Island; S., Sandy Hook; M., Montauk Point; Bl. Block Island.

strange absence of marine deposits, along the Atlantic Border, may be

accounted for by supposing that the dry land stretched farther to the eastward than now, and that seashore deposits were formed which are submerged. A change of level of five hundred feet would take a breadth of eighty miles from the ocean, and add it to the continent.

This important fact — which has been before referred to, more than once, on account of its bearing on the history of the continent — is presented to the eye in the accompanying map, prepared from one of the charts of the Coast Survey. The dotted lines (lines of equal soundings) run back in a long loop northwestward, toward New York harbor, showing deeper water along this line, and evidently proving that once the land was above water, with the Hudson River occupying this channel on its way to the ocean. At two or three places along this channel, there are "deep holes," as they are called (one of them at 32, where the depth is thirty-two fathoms), which may have been former sites of New York harbor; for the waters of the harbor are now about six fathoms deeper than those about its entrance. An under-water channel of the Connecticut also is indicated at c, c', c''.

This border, now submerged, has, therefore, in former time, been dry land; it may have been partly so in the Triassic period, and thus have caused the imperfect connection of the Triassic areas of the Atlantic Border with the ocean.

The Triassic continent spread westward to Kansas, and southward to Alabama; for, through this great area, there are no rocks more recent than the Paleozoic.

While, on the east, the continent probably stood above its present level, through the Triassic period, and while, over much of the Rocky Mountain region, the land was barely emerging from the waters, or was covered by interior salt seas, — farther west, over a large part of the Great Plateau, and the rest of the Pacific slope, the surface was washed by the waves of the Pacific, and peopled with its life. The Sierra Nevada was then no barrier to the ocean; for the sands, mud, and limestone accumulated in those waters constitute some of its rocks. The stratified beds of the mountains were then in progress of formation, through the action of the Pacific tides, currents, and waves, and the growth of marine life. The making of the Sierra was delayed till the rocks of still another geological period had been deposited upon the Triassic.

2. Foreign Triassic.

The region over which Triassic rocks outcrop, in England (see map on p. 344), stretches across the island, from a point in its southwestern part on the British Channel, north-northeastward; and also, from the centre of this band, along a northwestward course, to Liverpool, and

thence north, up the west coast. It is probable that all of England, east of the Triassic, was submerged. The rest of it was divided into three or more parts, — a southwestern (the peninsula of Cornwall and Devon), a western (Wales), and a northern, — indicating the existence of an archipelago of British Isles in the Triassic period. The rocks show that the waters between the islands were shallow and partly brackish.

In Europe, the Trias is found largely developed in regions east and west of the Rhine, from northern Switzerland northward; on the east side, through Wurtemberg, Odenwald, Thuringerwald, and by Giessen; and on the west side, along the Vosges, by Strasbourg and Metz, to Aix; and, in each of these regions, they indicate brackish or shallow waters, instead of deep seas. The beds occur also in other parts of central Europe, in the eastern Alps, Poland, Russia, Spain, etc., and in the far north, on Spitzbergen.

I. Rocks: kinds and distribution.

The subdivisions of the Trias are, — (1) the Variegated Sandstone; (2) the Shell Limestone; (3) the Red Marls, or the Keuper; (4) the Rhætic beds, between the Trias and Lias. The rocks are mainly red sandstones and marlytes, with an impure limestone as the middle member, in Germany. There is a "bone-bed" near the top of the series, both in England and Germany.

The subdivisions recognized in France and Germany are *three* in number; whence the name, from the Latin *tria, three*. The beds are denominated, in these countries and England, beginning with the lowest: —

I. *England.*	II. *France.*	III. *Germany.*
Saliferous beds, or New Red Sandstone, 1,200 to 2,500 feet.	1. Grès bigarré. 2. Calcaire coquillier. 3. Marnes irisées.	1. Bunter Sandstein, 1,200 to 1,600 ft. 2. Muschelkalk, 1,000 to 1,200 feet. 3. Keuper.

In English works, the names of the European beds, translated, are, — 1. Variegated sandstone; 2. Shell limestone; 3. Red marlytes, or Keuper; yet they are often written without translation. The names indicate the kinds of rocks. In England, they are sandstone and mottled clays (marlytes), mostly red. In Europe, near the Rhine, a thick fossiliferous impure limestone lies between a sandstone below and marlytes above. The formation is sometimes called the *Pœcilitic* (or, badly, Poikilitic), from the Greek for *variegated.*

This formation contains the principal salt-beds of Europe; and hence it is often called the *Saliferous system.* The salt in Germany is connected with the middle group, as in Wurtemberg, where there are noted salt works. In Vic and Dieuze, France, they are in the upper; and a thickness of 180 feet of rock-salt occurs in the course of 650 feet of rock. The salt layers alternate with clay and gypsum or anhydrite. In England, the upper part affords the salt; and at Northwich, in Cheshire, two beds of salt, nearly pure, are 90 to 100 feet thick.

St. Cassian series. — The beds of the St. Cassian series include, beginning below, —

A	1. Werfen beds, shale, sandstone, gypsum, salt.	
	2. Guttenstein beds, shale and limestone	150 feet.
	3. St. Cassian beds, red, pink, and white limestone, at St. Cassian and Hallstatt	800 feet.
B	4. Dachstein beds, white and grayish limestone	2,000 feet.
	5. Kössen beds (*Rhætic* of Gümbel, Upper St. Cassian of Escher and Merian), gray and black limestone and marls . . .	50 feet.

The Werfen beds are regarded as corresponding to the Bunter-sandstein; the Guttenstein, to the Muschelkalk and Lower Keuper; the St. Cassian, to the Middle Keuper; the Dachstein and Kössen, to the Upper Keuper. The Kössen beds are the Rhætic beds of Gümbel, and are by some referred to the Lower Lias. The St. Cassian beds of St. Cassian and Halstatt (between the head waters of the Inn and Drave, the former on the south, and the latter on the north side of the Austrian Alps), are remarkable for containing, among the 600 species of invertebrate fossils, many of Paleozoic genera, some of them not found elsewhere above the Permian. The Rhætic group in England (called the Penarth in the Government survey) includes beds of "the *Avicula contorta* zone", between the Trias and Lias. They occur in Dorset, Somerset, and Warwick to Lincolnshire. They include the "White Lias" of Wm. Smith, and the "landscape marble" of Cotham, near Bristol; and, next below these, black paper shales, with many fossils and a bone-bed, and then marlytes, mostly without fossils. The St. Cassian Series is sometimes called the "Alpine Trias."

II. Life.

The European Triassic beds have afforded teeth of one species of mammal, but fail of relics of birds.

1. *Plants.*

Equiseta, Ferns, Cypress evergreens, and Cycads (Fig. 739) are

Figs. 737–739.

Fig. 737, Voltzia heterophylla; 738, one of its fruit-bearing branches; 739, Pterophyllum Jægeri

the prevailing forms. No true Grass, Moss, Palm, or Angiosperm has yet been found in beds of this period.

Characteristic Species.

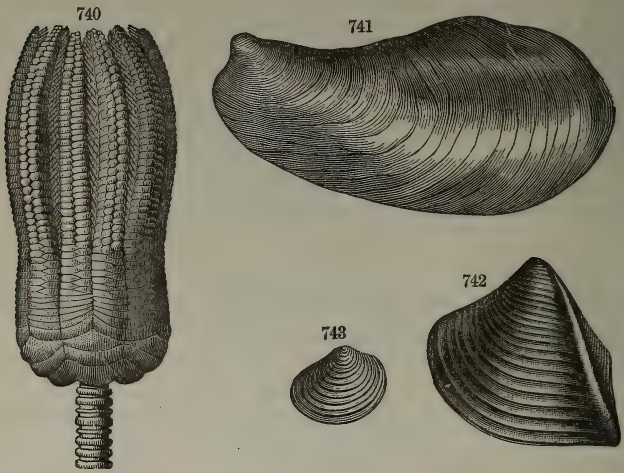
Figs. 737, 738, parts of branches of the *Voltzia heterophylla* Brngt., of the Cypress

group. Fig. 739, the Cycad *Pterophyllum Jægeri* Brngt., from Stuttgart. There are also species of *Equisetum*, *Calamites*, etc. Some names of European plants are given on p. 409. *Æthophyllum speciosum* Schp. & Mg., *Æ. stipulare* Schp., *Echinostachys oblonga* Brngt., and *E. cylindrica* Schp. & Mg., are names of species of grass-like plants referred to the Typhaceæ or "Cat-tail" family.

2. *Animals.*

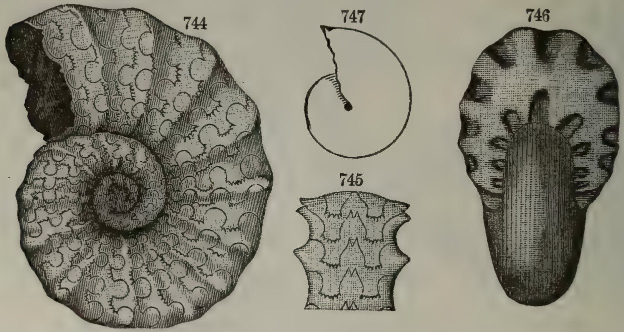
Radiates, though not abundant, are represented by Crinoids (Fig. 740, the "Lily Encrinite"), Star-fishes, and a few Corals.

Figs. 740–743.



CRINOID. — Fig. 740, Encrinus liliiformis. LAMELLIBRANCHS. — Fig. 741, Gervillia socialis; 742, Myophoria lineata. OSTRACOID. — Fig. 743, Estheria minuta.

Figs. 744–747.



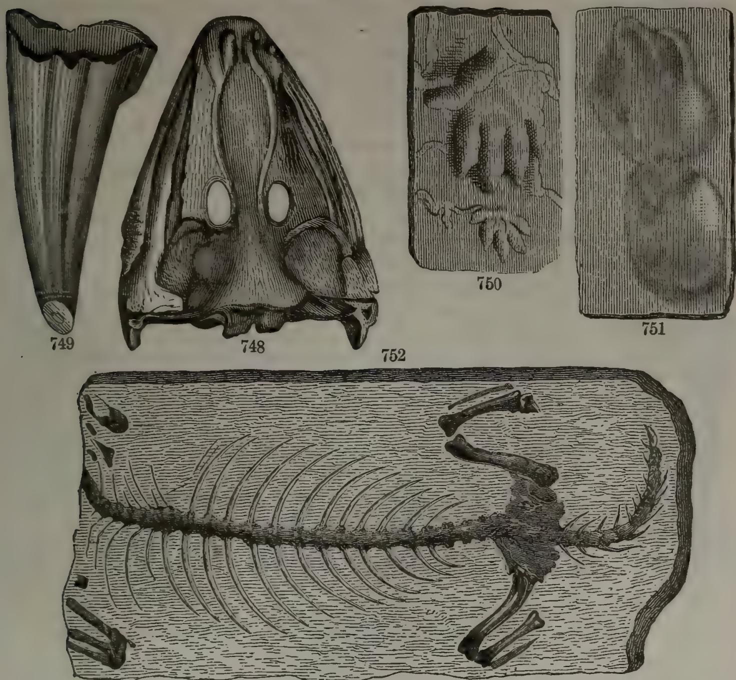
CEPHALOPODS. — Fig. 744, Ceratites nodosus; 745, dorsal view of portion of same, showing the dorsal lobes of the septa; 746, Ammonites tornatus; 747, side-view of same ($\times \frac{1}{2}$).

Mollusks were numerous, and among them species of the Ammonite group (Figs. 744, 746).

The Articulates included Insects, Crustaceans and Worms.

Among Vertebrates, the *Fishes* were all *Ganoids* or *Selachians*. The *Amphibians* comprised the gigantic *Labyrinthodon*, a scale-covered animal, of a Batrachian form, the skull of which (Fig. 748) was over

Figs. 748–752.



AMPHIBIANS. — Figs. 748, Mastodonsaurus giganteus $(\times\frac{1}{12})$; 749, tooth of same; 750, Cheirotherium $(\times\frac{1}{12})$: 751, track of turtle? TRUE REPTILES. — Fig. 752, Telerpeton Elginense.

two feet long, and the teeth (Fig. 749) three inches, — magnitude enough for the *Otozoum* of the Connecticut valley. The tracks (Fig. 750) referred to a genus named *Cheirotherium* (because of a resemblance in form to the human hand) are supposed to be those of a *Labyrinthodon*.

Fig. 753.

True Reptiles were represented by Swimming Saurians (Enaliosaurs); Rhynchosaurs, or Saurians with a beaked turtle-like mouth; Belodonts, between Lacertians and Crocodiles; and true Lacertians.

The species of Mammal, *Microlestes antiquus* Plien., a tooth of which is represented in Fig. 753, was a marsupial, and was closely related to that of North Carolina (p. 415).

Characteristic Species.

1. Radiates. — Fig. 740, *Encrinus liliiformis* Schlot., from the European "Muschelkalk." The limestone, in some places, is largely made up of Crinoidal remains. *Aspidura loricata* Ag., is a Star fish related to the *Ophiuræ*.

2. Mollusks. — (*a.*) *Brachiopods.* — *Terebratula vulgaris* Schlot., *Spirifer Münsteri* Dav., etc. (*b.*) *Conchifers.* — Fig. 741, *Gervillia socialis* Schlot. Fig. 742, *Myophoria lineata* Mü., of the Trigonia family; also *Lima striata* Desh., species of *Avicula*, *Pecten*, etc. (*c.*) *Cephalopods.* Fig. 744, *Ceratites nodosus* Schlot., related to the Ammonites (p. 400); 745, view of back of shell, showing shape of pockets: Fig. 746, *Ammonites tornatus* Braun, from the St. Cassian beds; 747, side view of same. Species of *Orthoceras* have been described from the same beds.

Fig. 754.

Pemphix Sueurii.

3. Articulates. — (*a.*) *Crustaceans.* — Ostracoids: Fig. 743, *Estheria* (*Posidonomya*) *minuta* Morris. — Macrourans: Fig. 754, *Pemphix Sueurii* Mey., a species near the Crawfish (genus *Astacus*). — (*b.*) *Insects.* — Species of *Curculionites*, *Glaphyroptera*, etc.

4. Vertebrates. — (*a.*) *Fishes.* — Among Hybodont Selachians, Fig. 509, *Hybodus plicatilis* Ag.; Fig. 508, *H. minor* Ag. Among Cestracionts, species of *Acrodus*, *Ceratodus*, etc. Ganoids, especially of the genera *Saurichthys*, *Gyrolepis*, *Amblypterus*, and *Palæoniscus*, the last of the heterocercal species; and, of the Pycnodont division, *Pycnodus gigas* Ag., etc.

(*b.*) *Amphibians* of the *Labyrinthodont* tribe: Fig. 748, *Mastodonsaurus giganteus* Jäg., reduced to one twelfth the natural size; Fig. 749, one of the teeth, reduced one half; they have the Labyrinthine structure, explained on p. 264; Fig. 750, prints of the fore and hind feet of a *Cheirotherium*, one twelfth natural size, from Hildburghausen, Saxony, supposed to be those of a *Mastodonsaurus*.

The larger track in one was eight inches long, with a stride of four inches; in another, twelve inches long. Similar tracks have been found at Storton, England. *Capitosaurus*, *Trematosaurus* are names of other great Labyrinthodonts of Europe.

(*c.*) *True Reptiles.* — *Enaliosaurs* (or Sea-Saurians), of the genera *Simosaur*, *Nothosaur*, *Pistosaur*, and *Conchiosaur*, occur, mostly in the Muschelkalk of Europe, and especially at Luneville, Bayreuth, and in Upper Silesia. They differ from the Jurassic Enaliosaurs in the extraordinarily large temporal, orbital, and nasal openings through the cranium, which leave little bone. The *Nothosaurus mirabilis* Mü. was about seven feet long. In the bone bed at the top of the Trias, in England, occur remains of two or three *Plesiosaurs* of the Lias, as *P. Hawkinsii* Ow. and *P. costatus* Ow., and of *Ichthyosaurs*, Sea-saurians of higher grade.

Lacertians and other Saurians. — Most of the species of the Trias have biconcave vertebræ, like the Thecodonts and Enaliosaurs (in this approximating to Fishes). A species of the Permian genus *Thecodontosaurus* is found in the Trias at Leamington, England. The turtle-headed *Rhynchosaurs* were among the most remarkable of Triassic Saurians.

Fig. 751, *Telerpeton Elginense* Mantell, a species found on the south side of the Moray Frith, in a whitish sandstone supposed to be Devonian, but now thought by most geologists to be Triassic. The animal is a Lacertian of modern type in most points, according to Huxley (Q. Jour. G. Soc., xxiii); this superiority to known Permian and Carboniferous Reptiles is partly the reason for making the beds Triassic. In the same rock, there were thirty-four consecutive footprints of an Amphibian. The genus *Belodon*, of Meyer, included carnivorous crocodile-like species.

Turtles. — Tracks like Fig. 751, observed in Germany, have been referred to a Turtle, the earliest representative of the tribe. The tracks form two *distant* parallel lines, as they should for an animal having a broad shell-covered body and short legs.

Coprolites of Reptiles are also common.

(*d.*) *Mammals.* — Fig. 753 represents the side-view of a tooth of *Microlestes antiquus* Plien., from the bone-breccia of Wurtemberg. A tooth of the same species was found at Frome, England. Owen regards the species as probably near the modern *Myrmecobius*, and closely related to another extinct Marsupial, *Plagiaulax*, of the English Upper Oölyte. Fig. 753 *a* shows the crown of the tooth.

Fossils characteristic of the subdivisions of the Trias. — The following are characteristic fossils of the three subdivisions of the Trias: —

1. Lower group. — *Voltzia heterophylla*, *Calamites Mougeoti* L. & H. *Neuropteris elegans* Brngt.; *Placodus impressus* Ag.; *Nothosaurus Schimperi* Mey.; *Trematosaurus;* footprints of Labyrinthodonts.

2. Middle group. — *Encrinus liliiformis*, *Gervillia socialis* Qu. (common to all the groups), *Myophoria* (*Trigonia*) *vulgaris* Br., *M. lineata* Mü., *Terebratula vulgaris*, *Ceratites nodosus*, *Nautilus bidorsatus* Br., *Pemphix Sueurii; Hybodus Mougeoti* Ag., H. *major* Ag., *Placodus* (several species); *Nothosaurus* (species differing from those of the lower group), *Simosaurus*, *Pistosaurus*.

3. Upper group, or Keuper. — *Equiseta*, *Calamites arenaceus* Jäg., *Pterophyllum Jægeri* Brngt., *Pt. longifolium* Brngt., *Pt.* (*Pterozamites*) *Münsteri* Göpp., *Mastodonsaurus giganteus*, *Belodon*, *Termatosaurus ; Microlestes antiquus*.

The *Estheria minuta* ranges through all the divisions.

The *St. Cassian* beds contain species of the Paleozoic genera *Orthoceras* (seven or eight species), *Cyrtoceras*, *Goniatites*, *Loxonema*, *Holopella*, *Murchisonia*, *Euomphalus*, *Porcellia* (*Bellerophon*), *Megalodon*, *Cyrtia*, which are not known afterward, along with others peculiarly Triassic, such as *Monotis salinaria* Br., *Halobia Lommeli* Wiss., *Myophoriæ*, *Ammonites.* The *Dachstein beds* contain, among their fossils, *Megalodon triqueter* Wulf., *Avicula intermedia* Emmr., *Spirifer Münsteri* Dav., *Sp. rostratus* Schloth., *Terebratula cornuta* Sow., *T. pyriformis* Suess, *T. gregaria* Suess, *Rhynchonella cornigera* Schafh., The *Kössen beds* have afforded an *Orthoceras*, a *Belemnite*, *Ammonites trisulcatus* Brngt., *Pleurotomaria expansa* Goldf., *Megalodon triqueter* Wulf., *Gervillia inflata* Schafh., *Avicula contorta* Portl., *A. inæquivalvis* Sow., *Lima gigantea* Sow., *Pinna folium* Phil., *Cardium Rhæticum* Merian, *Hemicardium Wulfeni*, *Pecten liasinus* Nyst., *Pecten Valoniensis* Defr., *Lithostrotion*, etc.

The Rhætic beds in England contain *Avicula contorta*, *Pecten Valoniensis* Defr. (these two species characteristic and abundant), *A. inæquivalvis*, *Cardium Rhæticum*, *Pullastra arenicola* Strickl., *Monotis decussata* Mü., *Modiola minima* Sow., *Ostrea liassica* Strickl.; *Spirifer Münsteri*, *Estheria minuta; Acrodus minimus* Ag., *Hybodus plicatilis*, *Saurichthys apicalis* Ag., *Gyrolepis tenuistriatus* Ag., vertebræ of *Ichthysosaurs* and *Plesiosaurs*, tracks of *Cheirotherium*; teeth of *Microlestes* (at Frome). Many of the species occur also in the Lias.

The Triassic rocks of Spitzbergen, partly bituminous shales, have afforded species of *Nautilus*, *Ammonites*, *Ceratites*, *Halobia*, etc., closely like, if not identical with, species of the St. Cassian beds (Laube).

3. General Observations on the Trias.

Life of the Period. — The steps of progress in the life of the globe, as the Mesozoic era opened in the Triassic period, were especially important. The storing away of the excess of atmospheric carbon, as coal, had purified the atmosphere; and, soon after the close of Paleozoic time — whose great feature was that its animal life had made rocks, and its plants, coal — there were higher races breathing the better air. Saurians became numerous; and the vertebrate type expanded by the appearance of species of the new class of Mammals

and probably also of that of Birds. Among these types, the Saurian continued rapidly to rise in perfection, with the following periods of the age; while Birds and Mammals remained of inferior types, the forerunners of an age of higher progress.

While Birds were just beginning, in long-tailed or Reptilian species, and Mammals in the semioviparous Marsupials, the corresponding inferior division of Reptiles, the Amphibians, here passed their culmination, the Labyrinthodonts ending and the Amphibians being afterward fewer and smaller.

Remarkable *harmony* of form characterized the higher terrestrial life. The group that gathered over the mud-flats of the Connecticut comprised the biped, scale-covered, crocodile-toothed Amphibians, from two or three inches to twelve or fifteen feet in height; Dinosaurs that could raise themselves erect, and march off like birds; Birds measuring height with the Amphibians, and outreaching them by their longer necks; and Marsupial Mammals with their hind-legs probably the longer, kangaroo-like. There was throughout a great development of the posterior extremities. All were oviparous vertebrates, except the semi-oviparous Marsupials.

The rocks, both in Europe and North America, were, to a large extent, of marsh, shallow-water, or estuary origin. But, on the borders of southwestern Austria, there was an open sea, with clear waters; and extensive limestone formations were in progress, thus anticipating the conditions that characterized much of Britain and Europe in the era of the Lias.

Climate. — The occurrence of the Trias in Spitzbergen, with some of its characteristic fossils, is evidence of a moderate climate in the Arctic. At the same time, the fact (learned from the St. Cassian beds) that many Paleozoic genera continued far into the Triassic era, and perhaps nearly to its close, south of the latitude of Vienna, while absent from northern Europe, appears to be evidence of unlike zones of temperature over that continent — a warmer southern half, and a colder northern. It is not improbable that the warm seas of the Indian Ocean then swept over southern Europe. It may be that the extermination of life terminating Paleozoic time — one of the most universal in geological history — was due to the intervening of an era of cold climate after, or cotemporaneously with, the mountain-making epoch which gave the Alleghanies birth; that the cold climatal conditions were brought on by Arctic elevations, as well as by upward movements of land in the higher temperate latitudes; and that the cold Arctic oceanic currents thus produced, to which the destructions of oceanic life were owing, did not affect so seriously parts of southern Europe, owing either to the lay of the emerged land, or to the Indian

Ocean current alluded to, or to both circumstances combined. The indications of floating ice, which Ramsay has found in the British Lower Permian, may have been a mark of the slow approach of such an era of cold.

2. JURASSIC PERIOD (17).

The Jurassic period derives its name from the Jura Mountains, on the western borders of Switzerland, one of the regions characterized by the formation.

1. American.

I. Rocks: kinds and distribution.

On the *Atlantic Border*, the upper portion of the formation described in the preceding pages, on the Triassic, may belong, as has been observed, to the Jurassic period. The absence of marine fossils leaves the question in doubt.

On the *Gulf Border*, there are no rocks of this period anywhere exposed to view.

In the *Western Interior region*, the Jurassic period may claim a part — perhaps a large part — of the gypsiferous beds referred to the Triassic; but fossils are here also wanting.

Apart from these doubtful beds, there are true Jurassic strata, full of marine fossils, overlying in many places the gypsiferous marlytes and sandstone. They have been observed about the Black Hills, the Laramie range, in Colorado, and other portions of the Rocky Mountain region; also over the Pacific slope, in the Uintah, Wahsatch, and Humboldt mountains, and in the Sierra Nevada. Whitney has found that Jurassic fossils occur in auriferous slates of the Sierra.

In the *Arctic region*, also, there are a number of localities of fossiliferous Jurassic strata.

The discovery and identification of the Jurassic of the Black Hills of Dakota were made by Hayden & Meek. The rocks occur also at Red Buttes on the North Platte, west of the Black Hills; also along the southwest side of the Big Horn Mountains (43½° N., 108° W.), and the northeast side of the Wind River Mountains; also beyond the Wind River Mountains, on the west; also about the head-waters of the Missouri — at all of which places fossils occur. (Hayden.) Other localities are near the valley of Green River, east of the Great Salt Lake, as announced by Meek & Engelmann; and near Fort Hall, in Idaho. The rocks observed are in general a gray or whitish marly or arenaceous limestone, with occasional purer compact limestone beds, intercalated with laminated marls. The thickness at the Black Hills is about 200 feet; on the northeast side of the Wind River Mountains, 800 to 1,000 feet; about Long's Peak, where the marlytes are absent, 50 to 100 feet. Another region of Jurassic rocks, on the north slope of the Uintah Mountains, has been described by Marsh. The rock is limestone (containing species of *Trigonia*, *Camptonectes*, *Chemnitzia*, etc.), overlaid by red gypsiferous beds, sandstone, and red and gray shales (containing *Belemnites densus*), in

all 360 feet in thickness. In the Wahsatch, Jurassic beds occur on the eastern side, beneath the Cretaceous.

In the auriferous slates of the Sierra Nevada, on the Mariposa estate, there occur *Aucella Erringtoni* Gabb, *Pholadomya* (?) *orbiculata* Gabb, *Belemnites Pacificus* Gabb; and other species in Genesee Valley, and probably at Spanish Flat, El Dorado County.

The Arctic localities are — the eastern shores of Prince Patrick's Land, in 76° 20′ N., 117° 20′ W.; the islands Exmouth and Talbe, north of Grinnell Land, 77° 10′ N., 95° W.; and Katmai Bay, or Cook's Inlet, in Northwest America, 60° N., 151° W.

II. Life.

Several of the genera of Radiates and Mollusks which mark the Jurassic beds of Europe have been found in the American Jurassic, the most prominent of which are *Pentacrinus*, *Trigonia*, *Ammonites*, and *Be-*

Figs. 755–760.

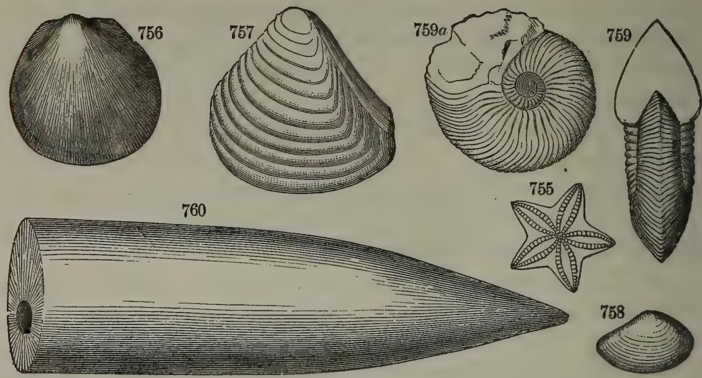


Fig. 755, a segment of the column of Pentacrinus asteriscus; 756, Monotis curta; 757, Trigonia Conradi; 758, Tancredia Warreniana; 759, Ammonites cordiformis; 759 *a*, Side-view of same, a little reduced; 760, Belemnites densus.

lemnites. The characteristics of *Ammonites* are briefly mentioned on p. 124, and again on p. 409. The fossil Belemnite (Fig. 760) is the internal bone, or *osselet*, of a Cephalopod, answering to the *pen* of the squid (Fig. 159, p. 119). They are much heavier than the same part in any modern species. The fossil represented in Fig. 760 is really only the lower and stouter part of the osselet: its structure is radiately fibrous. It has a conical cavity (or *alveolus*) within, opening upward, and at the bottom of this cavity there is, when it is perfect, a small chambered cone called the *phragmocone*, which has a siphuncle. The osselet, when unbroken, has a thin edge, and is further prolonged on one side into a delicate concave blade, a variety of which is shown in Fig. 792, on p. 440. The animal was much like that of a Sepia (see Fig. 159, p. 119); and its ink-bag was contained within the cavity of the osselet. The first species of the genus known was found in the

Upper Triassic. An Ammonite is represented in Figs. 759, 759 *a;* a species of the genus *Trigonia*, in Fig. 757.

Reptiles. — Remains of gigantic Reptiles occur in the Upper Jurassic of Colorado (near Morrison and Cañon City) and of Wyoming, in beds called by Marsh, their first describer, Atlantosaurus beds. They include *Dinosaurs*, both herbivorous and carnivorous, *Crocodilians*, *Pterodactyls* or flying-reptiles (see p. 446), and *Tortoises*, along with fishes of the genus *Ceratodus*. The *Dinosaurs* were either (1) *Saurian-footed*, having four or five toes to the hind-foot; or (2) *Bird-footed*, having three toes to the same. Of the former a species of *Atlantosaurus* (*A. immanis* Marsh) had a femur *over eight feet long*, and a total length of nearly 100 feet; the related *Morosaurus grandis* Marsh (Plate I.), was forty feet long; and *Apatosaurus Ajax* (Plate II.), had the vertebræ of the neck (Fig. 1) *four feet broad*, and a sacrum of three united vertebræ (Fig. 3). Of the latter division, the slender *Laosaurus altus* Marsh, about ten feet long, was strikingly bird-like, Plate III.; and species of *Creosaurus* Marsh were carnivorous.

Mammals. — The marsupials, *Dryolestes priscus* Mh., *Stylacodon gracilis* Mh., and others occur with the above Reptiles. (See p. 852.)

Characteristic Species.

Animals. — 1. **Radiates.** — Fig. 755, *Pentacrinus asteriscus* M. & H.

2. **Mollusks.** — (*a.*) *Lamellibranchs.* — Fig. 756, *Monotis curta*, from the Black Hills; Fig. 757, *Trigonia Conradi* M. & H., ibid.; 758, *Tancredia Warreniana* M. & H., ibid. (*b.*) *Cephalopods.* — Fig. 759, young specimen of *Ammonites cordiformis* M. & H., ibid.; Fig. 759 *a*, side-view of the same; Fig. 760, *Belemnites densus* M. & H., the upper part broken away, ibid.

The Jurassic beds of Genesee valley, Plumas County, California, contain a *Belemnite*, *Trigonia pandicosta* M., a *Gryphæa* near *G. vesicularis* Br., *Inoceramus* (?) *obliquus* M., *I.* (?) *rectangulus* M., *Rhynchonella gnathophora* M., and others of the genera *Lima*, *Pecten*, *Mytilus*, *Astarte*, *Unicardium*, *Myacites*, and *Terebratula*. In the beds of the Uintah Mountains occur *Pentacrinus asteriscus*, *Belemnites densus*, two *Trigonias*, *Gryphæa calceola*, *Myophoria lineata*, *Camptonectes bellistriatus*, *Eumicrotis curta*, etc.

Among the Arctic fossils of this period, there are, at Prince Patrick's Land, *Ammonites M'Clintocki*, a species near *A. concavus* Sow., of the Lower Oölite; and at Cook's Inlet, *Ammonites Wosnessenski*, *A. biplex* Sow. (?), *Belemnites paxillosus* (*B. niger* List ?), and *Pleuromya unioides* Br. (*Unio liassinus* Schubler). *A. biplex* also is reported to occur in the Chilian Andes, in latitude 34° S., as well as in Britain and Europe.

2. Foreign.

I. Rocks: kinds and distribution.

The strata of the Jurassic period in England (see map, page 344, on which the areas numbered 7, 8 are Jurassic) appear at the surface over a narrow range of country (averaging thirty miles in width), commencing at Lyme-Regis and Portland on the British Channel, and extending across England, north of northeast, to the river Humber, and still farther north, on the eastern coast of Yorkshire, almost to

the mouth of the Tees. The Jurassic seas appear to have covered the eastern part of England; while the western part, from the north to Cornwall, was apparently an elevated barrier against the ocean. Jurassic beds also occur on the northeast coast of Ireland, as at the Giants' Causeway and on the Western Isles.

Following the line of the British Jurassic belt from Lyme-Regis and Portland across the English Channel, we come upon an apparent continuation of the belt in France. It sweeps south, by the borders of Brittany, to the central plateau of France, and then east and north, by the eastern boundary of the empire, thus surrounding a large area of which Paris is the centre.

The line of barrier-islands of western England is continued in Brittany, in western France; the line of the outcropping Jurassic, in similar outcropping Jurassic in France; and the area of the shallow Jurassic sea over eastern England, in the extensive Parisian basin, — a sea which was then the western and southern border of the German Ocean, and covered what are now the sites of London and Paris.

The central plateau of France — a region of crystalline rocks — is nearly encircled by Jurassic strata; and the rocks are continued eastward over the Jura Mountains (by Neufchatel), and along their continuation through Wurtemberg and Bavaria in southern Germany. They appear also in northern Germany (Westphalia) and the Alps (Savoy, etc.).

Jurassic beds occur also along the Andes in many regions, from their northern limit to Tierra del Fuego. They are found in many parts of Asia, and have been recognized by W. B. Clarke in Australia.

The Jurassic period, in England and Europe, is divided into three epochs: (1) the epoch of the *Lias*, or the *Liassic*, so designated from a provincial name of the rocks in England (No. 7 *a* on the map referred to); (2) the epoch of the *Oölyte,* or the *Oölytic* (No. 7 *b*), so called because a prominent rock of the series in England is oölyte (see p. 86); and (3) the epoch of the *Wealden* (No. 8 on map), named from a region called The Weald, in Kent, Surrey, and Sussex, where the beds were first studied. The Wealden are transition beds between the Jurassic and Cretaceous, and are often referred to the latter, although more closely related physically to the upper part of the former period.

The *Liassic* beds consist mainly of grayish limestones, containing marine fossils.

The *Oölytic* include limestones, part of which are oölitic in texture, and others arenaceous and clayey. One of the limestones is a coral-reef rock. All of the beds are of marine or sea-shore origin, as the fossils show, excepting strata in the local Purbeck beds near the top of the series, one of which, on the island of Portland, is called the Portland dirt-bed.

The *Wealden* is wholly of estuary or fresh-water origin; the beds consist of clays, sands, and, to a small extent, fresh-water limestone.

The promiment subdivisions of the Jurassic formation observed in England (though not present alike in all its Jurassic regions) are the following, beginning below: —

I. Lias.

1. *Lower Lias:* consisting of grayish laminated limestone, with shale above.
2. *Middle Lias:* a coarse shelly limestone, called marlstone.
3. *Upper Lias:* beds of clay or shale, with some thin limestone layers.

II. Oölyte.

1. *Lower* or *Bath Oölyte,* consisting of —
   (1.) *Inferior Oölyte,* a limestone with fossils and layers of sand.
   (2.) *Fuller's-earth* group, or clayey layers.
   (3.) *Great Oölyte,* limestone, mostly oölitic.
   (4.) *Forest-marble* group, sandy and clayey layers, with some oölite.
   (5.) *Cornbrash,* a coarse shelly limestone.

The *Stonesfield slates,* noted for their remains of Saurians, as well as of the earliest British Mammals, and also of Insects and other species, occur near Oxford in England, and belong to the Lower Oölyte, below the Great Oölyte.

At Brora, in Sutherlandshire, there is a bed of Oölytic coal of good quality, three and a half feet thick, which has been long worked: it is covered by several feet more of impure coal, containing pyrite. It is supposed to belong with the Great Oölyte.

2. *Middle* or *Oxford Oölyte:* consisting of —
   (1.) *Kelloway Rock,* a calcareous grit, overlying blue clay, and overlaid by (2.) the *Oxford clay.*
   (3.) Calcareous grit and oölitic coral limestone, called the *Coral Rag.*
3. *Upper* or *Portland Oölyte:* consisting of —
   (1.) *Kimmeridge Clay.*
   (2.) *Shotover Sand,* a calcareous rock with concretions.
   (3.) *Portland Oölyte.*
4. *Purbeck beds:* consisting of (1) the *Lower Purbeck,* fresh-water marls, with the "Portland dirt-bed," and resting on the upper layers of the "Portland stone;" (2) the *Middle Purbeck,* mostly a bed of marine limestone, 30 feet thick; (3) the *Upper Purbeck,* 50 feet of fresh-water deposits. The dirt-bed of the Purbeck is the second deposit affording remains of British Mammals. It contains also numerous remains of Cycads, etc.

III. Wealden.

1. *Hastings Sands:* sandstone, with some clayey and limestone layers, containing Saurian remains, fluviatile shells, etc.
2. *Weald Clay:* clayey layers, with some calcareous beds containing fresh-water shells.

The British subdivisions are for the most part recognized in France, and have received special names from D'Orbigny. They are (I.) in the Lias, — 1, the *Sinemurian* (Lower Lias, named from the locality at Sémur); 2, *Liasian* (Middle Lias); 3, *Toarcian* (from the locality at Thours); (II.) in the Oölyte, — 1, *Bajocian* (the inferior part of the Lower Oölyte, named from the locality at Bayeux); 2, *Bathonian* (the Great Oölyte, Bath Oölyte): 3, *Callovian* (Kelloway Rock); 4, *Oxfordian* (Oxford Clay); 5, *Corallian* (Coral Rag); 6, *Kimmeridgian* (Kimmeridge Clay); 7, *Portlandian* (Portland Oölyte). In the French Juras, the Lias limestone is called also *Gryphite* limestone, from the abundance of the fossil *Gryphæa incurva.*

For the "Inferior Oölyte" Marcou has used the name *Lædonian;* for the Fuller's earth, *Vesulian.* Thurman and Etallon have restricted *Corallian* to the lower part of the *Corallian* of D'Orbigny (the part called *Rauracian* by Creppin), and named the upper part, commencing with the beds containing *Astarte minima* and including the lower part of the Kimmeridge clay, the *Astartian* (the same is the *Sequanian* of M. Jourdy); the *Kimmeridgian,* comprising the middle part of the Kimmeridge Clay, is the *Strombian* of Thurmann. The Portland Oölyte is the *Portlandian* of Marcou (or *Virgulian* of Thurmann); and, lastly, the *Purbeckian* is the *Dublisian* of Desor and *Tithonic* of Oppel. The Wealden is *Lower Neocomian* of D'Orbigny.

The famous beds of *Lithographic slate* at Solenhofen, a very fine-grained calcareous rock, affording remains of many Insects, several species of Saurians, Pterodactyls, etc., are situated in the district of Pappenheim in Bavaria, and are of the age of the Middle Oölyte, or that of the Coral Limestone.

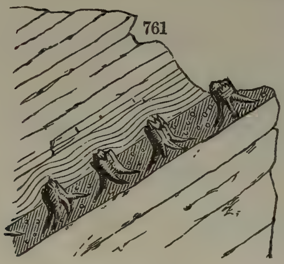
II. Life.

1. *Plants.*

The land-plants of the Jurassic period were mainly *Ferns*, *Conifers*, and *Cycads*, as in the Triassic. Leaves and stems are found in many

Figs. 761, 762.

761



762

Fig. 761, Section from near Lullworth Cove, showing stumps of trees (*a*) in the Portland "dirt bed;" 762, stump of the Cycad, Mantellia (Cycadeoidea) megalophylla ($\times \frac{1}{12}$).

of the strata, and remains of a forest in what is called the Portland dirt-bed (Fig. 761), the trees of which were Conifers and Cycads. Figure 762 represents, much reduced, one of the Cycad stumps. Near Whitby, on the sea-coast of Yorkshire, and in the Stonesfield slate, fossil ferns are common.

No Jurassic *Angiosperms* are known.

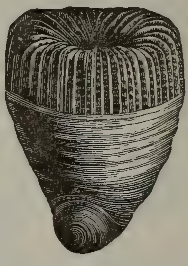
2. *Animals.*

Sponges were not uncommon; one kind is shown in Fig. 768. The

Figs. 768–770.

768

769



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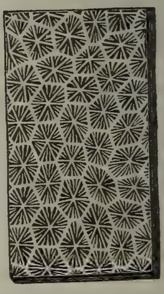
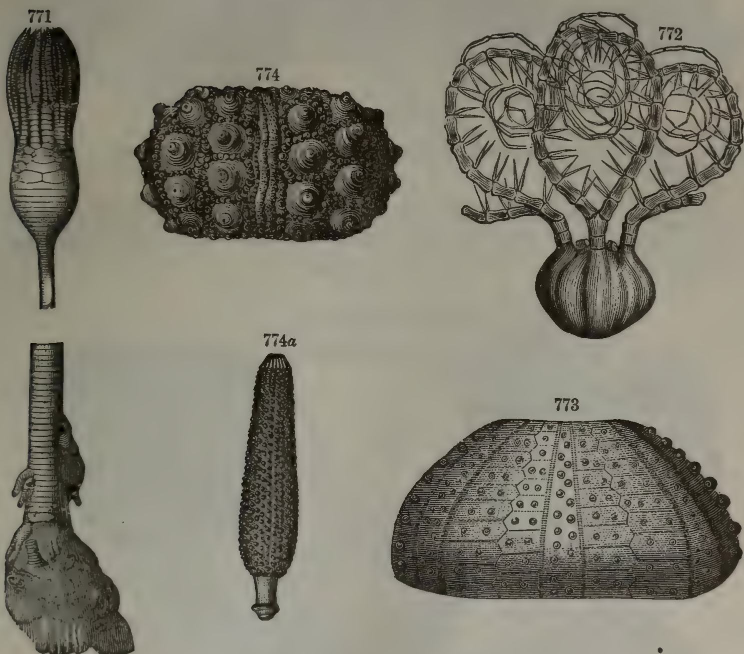


Sponge, of the Oölyte. — Fig. 768, Scyphia reticulata. Polyp-Corals, of the Oölyte. — Fig. 769, Montlivaltia caryophyllata; 770, Prionastræa oblonga.

earliest known of the coin-shaped Rhizopods, called *Nummulites* and *Orbitolites*, occur in Jurassic beds of Franconia, Germany. (A Tertiary species is figured on p. 499.) *Corals* are of various kinds (Figs. 769, 770), and many have a modern look. Among Echinoderms, there were Crinoids, mostly of the genera *Pentacrinus* and *Apiocrinus*, a species of the latter of which (*minus* a part of its long stem) is represented, reduced, in Fig. 771; also free Crinoids of the Comatula type (Fig. 772), as well as many Star-fishes; also Echinoids (Figs. 773, 774), many with very stout spines, as in Fig. 774 *a*.

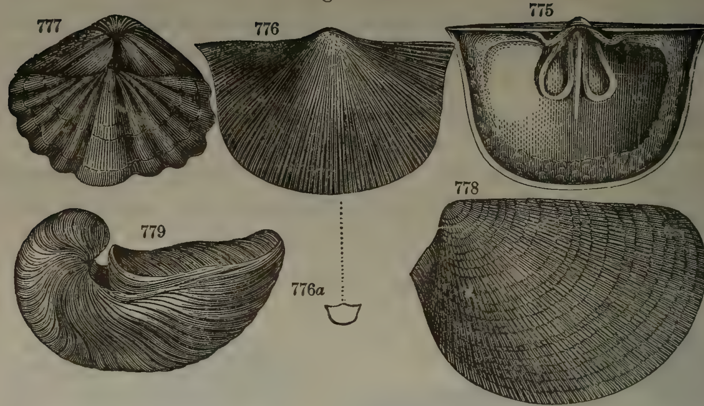
Figs. 771–774.



ECHINODERMS. — Fig. 771, Apiocrinus Roissyanus (× ¼), the middle part of the stem omitted; 772, Saccocoma pectinata; 773, Diademopsis seriale; 774, Cidaris Blumenbachii; 774 *a*, spine of the last. All Oölytic, excepting the last, which is Liassic.

Among *Mollusks*, there was a great variety of new forms, many peculiar to the Mesozoic era. The last of the Brachiopods of the *Spirifer* and *Leptæna* families appeared in the Lias (Figs. 775–777). These *Leptænæ* were minute species (Fig. 776 *a*), contrasting wonderfully with the abundant and large *Leptænæ* of the Silurian, when the family was at its maximum. The prevailing Brachiopods were of the modern genera *Terebratula* and *Rhynchonella*.

Figs. 775–779.



Brachiopods and **Lamellibranchs**, of the Lias.—Figs. 775, 776, Leptæna Moorei (×7); 776 *a*, same, natural size; 777, Spirifer Walcotti; 778, Lima (Plagiostoma) gigantea (×⅓); 779, Gryphæa incurva (×⅔).

Lamellibranchs comprised several new genera. *Gryphæa* (Figs. 779, 782), of the Oyster family, having an incurved beak, commenced in the Lias, and was a characteristic kind.

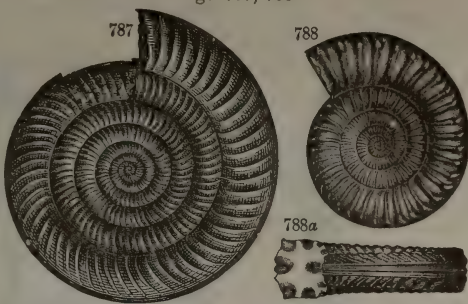
Figs. 780–785.

Lamellibranchs, of Oölyte.—Fig. 780, Ostrea Marshii; 781, Exogyra virgula; 782, Gryphæa dila tata; 783, Trigonia clavellata; 784, Astarte minima: 785, Diceras arietina.

The Gasteropods were represented by several new modern genera, besides others that are now extinct. One of the more peculiar forms

Fig. 786.

Figs. 787, 788.

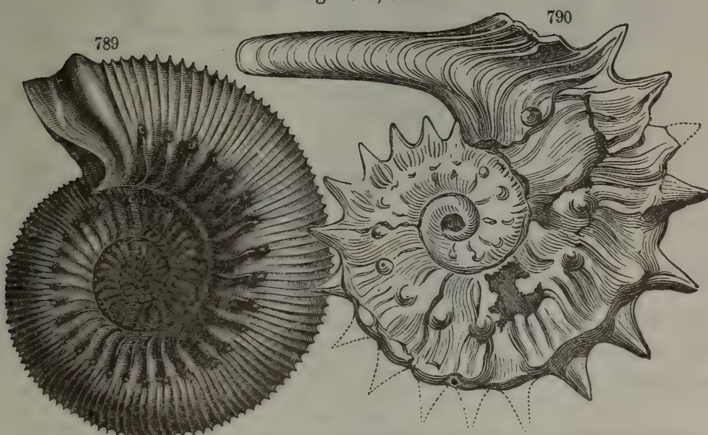


GASTEROPOD. — Fig. 786, Nerinæa Goodhallii. CEPHALOPODS. — Fig. 787, Ammonites spinatus; 788, A. Bucklandi.

was that of the genus *Nerinæa* (Fig. 786), in which the spiral cavity has one or more ridges, as shown in Fig. *b*.

But the type of Cephalopods especially underwent great expansion.

Figs. 789, 790.



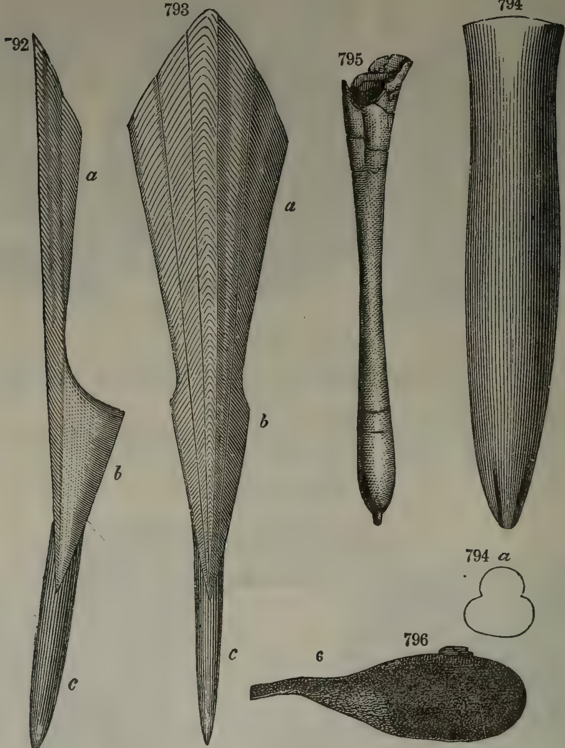
CEPHALOPODS. — Fig. 789, Ammonites Humphreysianus; 790, A. Jason.

The group of *Ammonites* abounded in species. Figs. 787, 788, are Liassic species; and Figs. 789, 790, others from the Oölyte. The last two figures have the aperture unbroken; and in 790 it is much prolonged on either side.

In addition to these Cephalopods with external chambered shells (Tetrabranchs or Tentaculifers), there were also those having an internal shell or bone (Dibranchs or Acetabulifers), a group which

includes very nearly all known existing species. The most abundant of these were the *Belemnites*, already described on page 432. Figs.

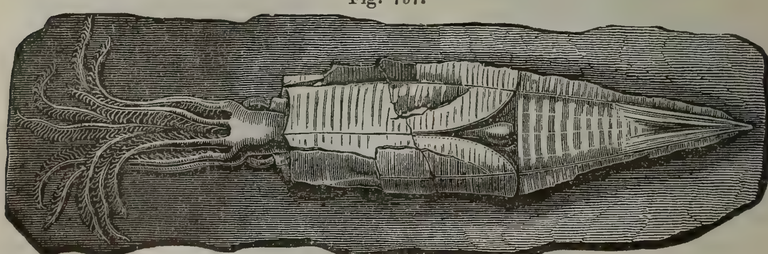
Figs. 792–796.



CEPHALOPODS. — Fig. 792, Complete osselet of a Belemnite, side-view, reduced; 793, dorsal view of same; 794, *a*, B. paxillosus ; 795, B. clavatus ; 796, Ink-bag.

794, 795 represent the bones or osselets of two species, in their ordinary broken state; and Figs. 792, 793 an unbroken one, in two different positions.

Fig. 797.

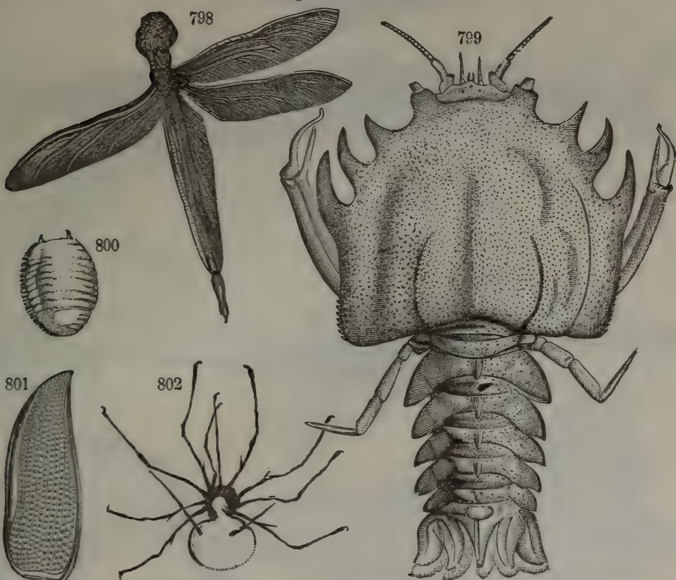


Acanthoteuthis antiquus (×⅓), of the Oölyte.

Fig. 797 represents the animal of an allied genus, called *Acanthoteuthis.* There were also species of the Sepia or Cuttle-fish family, and Calamaries or Squids; and the ink-bags of these species are sometimes found fossil (Fig. 796), and also the smaller ones of *Belemnites.* Buckland states that he had drawings of the remains of extinct species of *Sepia* made with their own ink.

The sub-kingdom of *Articulates* was represented by various Worms, Crustaceans, Spiders, and Insects; and, of the last, all the principal tribes appear to have been represented, even to the highest, the Hymenopters. Figs. 799, 800 are Crustaceans of the Oölyte, from Solenhofen; 798, 801, remains of Insects; 798, a Dragon-fly, or *Libellula* (Neuropter); 801, the wing-case of a Beetle (Coleopter), from Stonesfield. Fig. 802 is one of the Spiders. The oldest known (in 1873) British Crab, a long-legged Triangular Crab (*Palæinachus longipes* Woodward), comes from the Lower Oölyte.

Figs. 798–802.



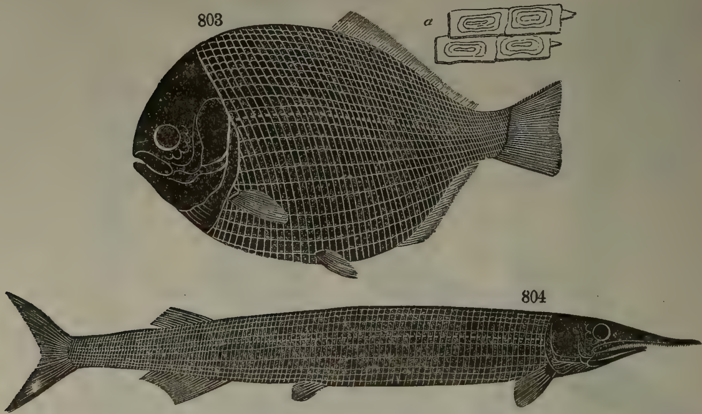
ARTICULATES. — Fig. 798, Libellula; 799, Eryon arctiformis; 800, Archæoniscus Brodiei; 801 elytron or wing-case of Buprestis; 802, Palpipes priscus.

The sub-kingdom of Vertebrates included species of Birds, as well as Fishes, Reptiles, and Mammals.

FISHES. — The Fishes were almost solely Ganoids and Selachians; but none of the former have vertebrated tails, this Paleozoic feature having disappeared.

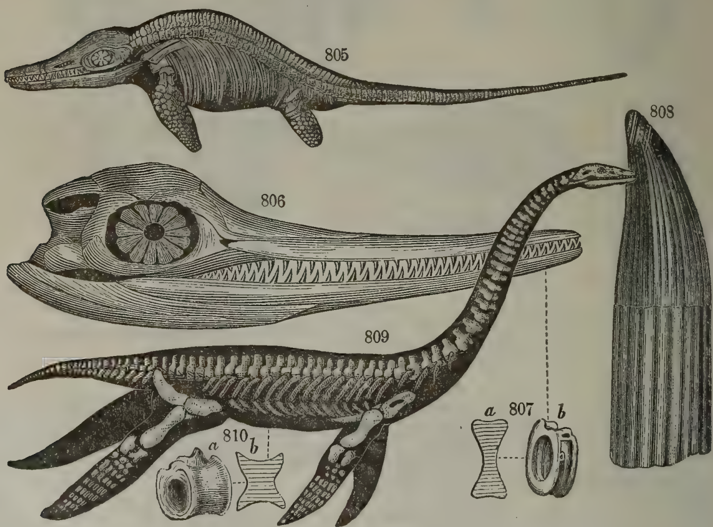
The *Teliosts* or *Osseous fishes* are supposed also to have had here their first species; but they were little numerous, compared with the other kinds, or with their abundance in the next, or Cretaceous, period.

Figs. 803, 804.



GANOIDS. — Fig. 803, Æchmodus (Tetragonolepis) ($\times\frac{1}{6}$), from the Lias; *a*, Scales of same; 804 Aspidorhyncus ($\times\frac{1}{8}$), from the Oölyte.

Figs. 805–810.



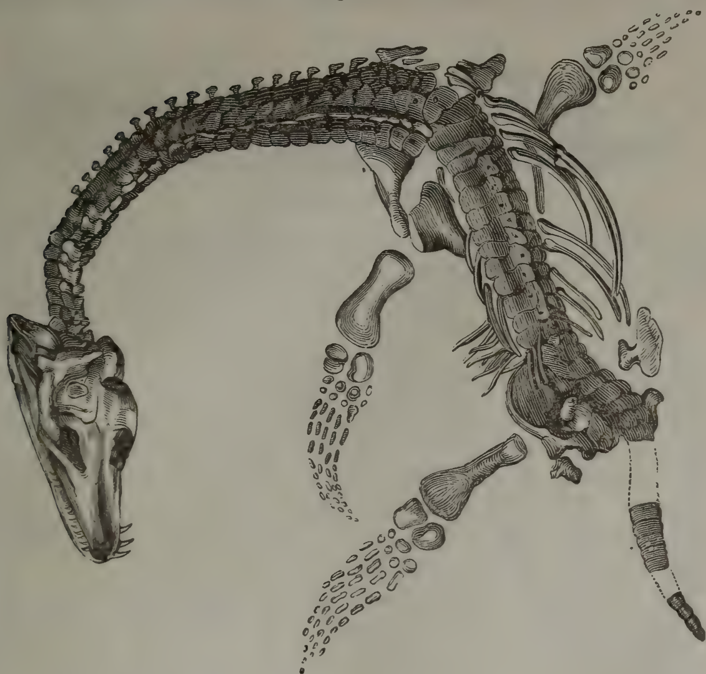
REPTILES. — Fig. 805, Ichthyosaurus communis ($\times\frac{1}{100}$); 806, Head of same ($\times\frac{1}{30}$); 807 *a*, *b* view and section of vertebra of same ($\times\frac{1}{3}$); 808, Tooth of same, natural size; 809, Plesiosaurus dolichodeirus ($\times\frac{1}{80}$); 810 *a*, 810 *b*, view and section of vertebra of same.

REPTILES. — During this era, the Reptilian type underwent an

expansion more remarkable than that of Cephalopods. The true Reptiles were represented by numerous Enaliosaurs (sea-saurians, p. 339), of higher grade than the Simosaurs of the Triassic, as is shown in their solid bony skulls; by Lacertians and Crocodilians, many of which were 15 to 50 feet in length; by great Dinosaurs, the highest of Reptiles; by Flying Saurians (Pterosaurs), having wings, much like Bats; by Turtles of several genera.

(1.) *Enaliosaurs* or *Swimming Saurians.* — The more common genera of Enaliosaurs are the *Ichthyosaurus*, *Plesiosaurus* and *Pliosaurus.* The Ichthyosaurs (the name, from the Greek, signifiying *fish-lizard)* were gigantic animals, 10 to 40 feet long, having paddles some-

Fig. 811.



REPTILE — Plesiosaurus macrocephalus ($\times\frac{1}{40}$).

what like the Whale (Fig. 805), long head and jaws, numerous (in some species 200) stout, conical, striated teeth (Fig. 808), an eye of enormous dimensions (as shown in Fig. 806), thin, disk-shaped, biconcave vertebræ (Figs. 807 *a*, 807 *b*). The *I. communis*, found in the Lias of Lyme-Regis and elsewhere, was 28 or 30 feet long.

The *Plesiosaur* (the name meaning *allied to a Saurian*), (Figs. 809,

811) had a long, snake-like neck, consisting of twenty to forty vertebræ, a small head, short body, paddles, and biconcave vertebræ differing little in length and breadth. *P. dolichodeirus* (Fig. 809) was 25 to 30 feet long. *P. macrocephalus* is represented in Fig. 811, just as it lay in the rocks. The British rocks of the Jurassic and Cretaceous periods have afforded sixteen species of Plesiosaurs; and twenty-one, in all, are known, of which twelve were found in the Lias, and seven in the Oölyte. The *Pliosaurs* were other swimming Saurians, near the Plesiosaur: some individuals were thirty to forty feet long. Remains of more than fifty species of Enaliosaurs have been found in the Jurassic rocks.

(2.) *Crocodilians.* — Many of the Crocodilians were of the Teleosaur type, having slender jaws like the Gavial, but biconcave verte-

Fig. 812.

Mystriosaurus Tiedmanni.

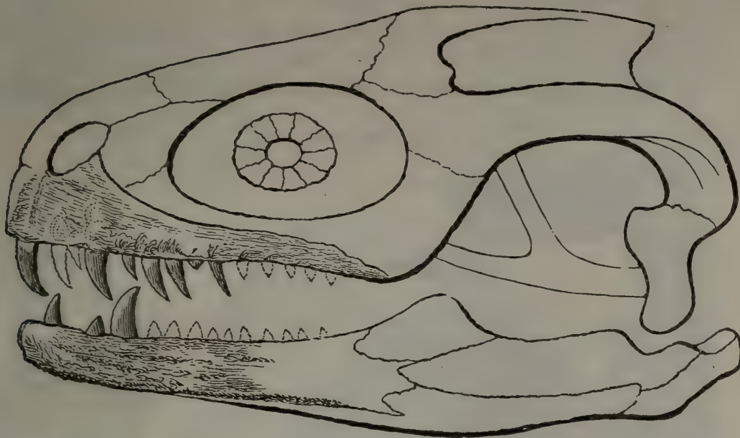
bræ, — the latter a mark of both antiquity and inferiority. Fig. 812 represents the skull of one of these species, the *Mystriosaur*.

Another and larger Crocodilian was the *Cetiosaur*, from the Oölyte, an animal at least fifty feet in length, "not less than ten feet in height when standing, and of a bulk in proportion," and "unmatched in magnitude and physical strength by any of the largest inhabitants of the Mesozoic land or sea." (J. Phillips.) One of the fossil femurs (thigh-bones) is 64 inches long, nearly a foot in diameter at middle, and $20\frac{3}{4}$ inches at the upper extremity. The food was probably vegetable. The caudal vertebræ were biconcave, while the dorsal were convexo-concave. Cetiosaurian remains occur in the Oölyte, from the Lower beds to the Wealden.

(3.) *Dinosaurs.* — Still other famous Crocodile-like animals were the *Megalosaurs*, carnivorous Reptiles, whose remains occur in the Lias, Oölyte, and Wealden. *M. Bucklandi* is the species best known. It was twenty-five or thirty feet long, with the hind limbs twice the longer and stouter. It waded in the waters, or prowled over the land, moving about — "not as a ground-crawler, like the Alligator, but with free steps, and chiefly, if not solely, on the hind limbs, claiming thus a curious analogy, if not some degree of affinity, with the Ostrich." (J. Phillips.) It had a few large teeth, with sharp crenulated edges. The limb bones seem to have been hollow, — one of its bird-like characteristics, — while the hind feet were probably three-

toed, like those of other Dinosaurs, with strong compressed claw-bones. The sacrum corresponded, as in Mammals, to five united

Fig. 813.



Megalosaurus Bucklandi ($\times\frac{1}{10}$) as restored by Phillips.

vertebræ. This Reptilian Carnivore was of very high grade in its class, higher than the huger Cetiosaur; it compared in size with the Cetiosaur, nearly as the highest Mammalian Carnivores with the Elephantine Herbivores.

Fig. 814.

Tooth of Iguanodon Mantelli

The *Iguanodon* of Mantell was an herbivorous Dinosaur of the Wealden. It was thirty feet long, and of great bulk, and had the habit of a Hippopotamus. The femur, or thigh-bone, in a large individual, was about thirty-three inches long, and the humerus, nineteen inches. The teeth (Fig. 814) were flat, and had a serrated cutting edge like the teeth of the *Iguana;* and hence the name, signifying *Iguana-like teeth:* many of them, from old animals, are worn off short. This species occurs also in the Cretaceous.

The *Hylæosaur*, another Tilgate Forest Dinosaur, had its skin covered with circular or elliptical plates, and was twenty to twenty-two feet long.

The Coprolites (fossil excrements) of the Saurians are not uncommon; one is represented in Fig. 816. They are sometimes silicified, and, notwithstanding their origin, are beautiful objects, when sliced and polished.

(4.) *Pterosaurs or Flying lizards.* — The flying lizards were of several genera, the first known of which is *Pterodactylus* — so named from the Greek for *wing* and *finger*, the outer finger of the hand being greatly prolonged, to serve as a support for the expanded membrane of the side of the body and limb, and the whole thus making a wing or flying organ, analogous to that of a Bat.

Fig. 815 represents the skeleton (reduced in size) of *P. crassirostris*,

Figs. 815, 816.

815

816

PTEROSAUR. — Fig. 815, Pterodactylus crassirostris (× ¼); 81 , Coprolite.

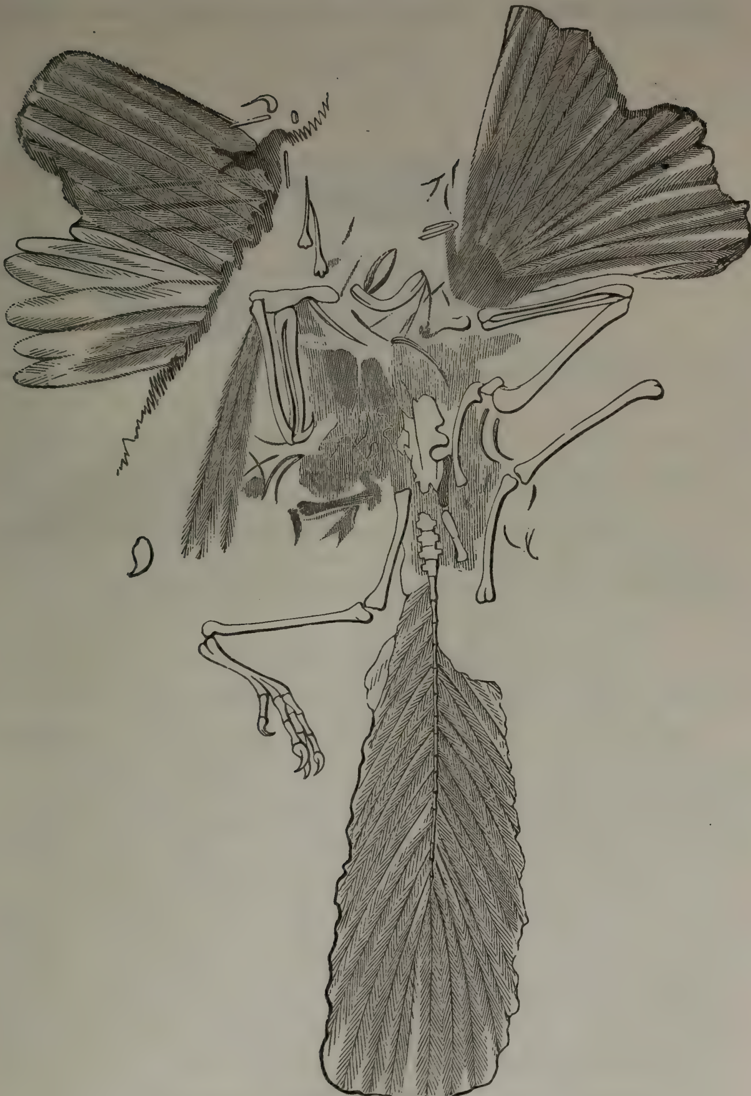
The species was a foot in length; and the spread of the wings was about three feet. As in Birds, the bones of Pterodactyls are hollow, to fit them for flying; but, unlike Birds, they have the skin, claws and teeth of Reptiles. Their habits were those of bats rather than birds. They range from the Lias into the Chalk.

BIRDS. — Birds occur fossil at Solenhofen, both their bones and impressions of their feathers. A specimen there found is represented in Fig. 817, reduced to one fourth its natural size. The Bird, named by Owen *Archæopteryx macrura* (meaning *long tailed ancient-bird*), had a tail of 20 vertebræ, 11 inches long and 3½ inches broad, with a row of feathers along either side, a pair to each caudal vertebra. The wing appears to have had a two-jointed finger.

MAMMALS. — The Mammals of the Jurassic have been found in the Lower Oölyte at Stonesfield, and in the Middle Purbeck beds of the Upper Oölyte.

The relics from the Stonesfield slate (a bed of shelly limestone only six feet thick) are referred to Marsupials, Fig. 818 represents the jawbone of the *Amphitherium* (*Thylacotherium*) *Broderipii*, and Fig.

Fig. 817.

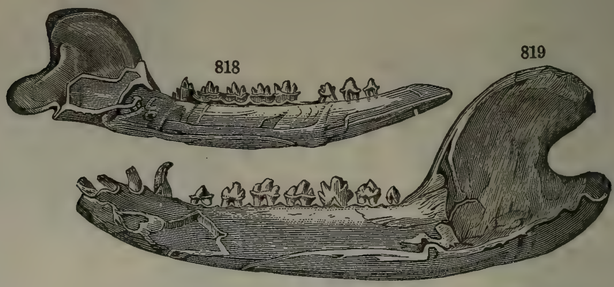


Archæopteryx macrura.

819 the same of the *Phascolotherium Bucklandi*, — each twice the size of nature. The former species, according to Owen, is most nearly related to the Marsupial Insectivores. The lower jaw of another genus, called *Stereognathus*, has been found in the same bed.

The Middle Purbeck has afforded relics of about fourteen species of Mammals, along with fresh-water shells and Insects. The species

Figs. 818, 819.



MAMMALS. — Fig. 818, Amphitherium (Thylacotherium) Broderipii (× 2); 819, Phascolotherium Bucklandi (× 2).

have been referred mostly to the Insectivorous Marsupials; but two species, of the genus *Plagiaulax*, have the teeth of Rodents, and were related to the Kangaroo-rat; while another, of the genus *Galastes*, as large as a polecat, was a Predaceous Marsupial. The remains of the Purbeck were all "obtained from an area less than 500 square yards in extent, and from a single stratum but a few inches thick."

Characteristic Species.

1. *Liassic Epoch.* (L. stands for Lower Lias, M. for Middle, and U. for Upper.)

1. Radiates. — POLYP CORALS. — *Isastræa Stricklandi* Duncan, L.; *Montlivaltia Guettardi* Dfr., L.; *M. mucronata* Dunc., L.; *M. cuneata* Dunc., M.; *Thecocyathus rugosus* Dunc., L.; *Thecosmilia Tarquemi* Dunc., L. (genera of corals widely different from the Paleozoic); CRINOIDS, *Pentacrinus Briareus* Mill., L.; *P. basaltiformis* Mill., L.; ECHINOIDS, Fig. 773, *Diadema seriale* Ag., L.; *Cidaris Edwardsii* Wright, L. British Liassic species of Holothuria have been made out, from the occurrence of minute wheel-shaped calcareous pieces, such as are found in some sections of the tribe.

2. Mollusks. — BRACHIOPODS, Fig. 777, *Spirifer Walcotti* Sow., L., and M.; *Terebratula numismalis* Lam., L., and M.; *T. rimosa* Buck, M.; *Rhynchonella acuta* Sow., L.; Figs. 775, 776, Leptæna *Moorei* Dav., U.; 776 *a*, natural size; *R. variabilis* D'Orb., L. Five species of *Leptæna* and about twice as many *Spirifers* occur in the Lias. While these old Silurian genera were disappearing, the new Brachiopod genus *Thecidea* began; and with it there were *Lingulæ, Rhynchonellæ*, and *Craniæ*, and many *Terebratulæ*. The genera *Rhynchonella* and *Crania*, it should be remembered, are lines reaching from the Silurian to the present time; and *Terebratula* dates back to the Devonian.

LAMELLIBRANCHS. — Fig. 779, *Gryphæa incurva* Sow., L. (Gryphite Limestone); *G. gigantea* Sow., M.; *G. cymbium* Lam., M.; *Gervillia crassa* Buckm., L.; *Ostrea liassica* Strickl., L.; *O. Knorrii* Voltz, U.; Fig. 778, *Lima* (*Plagiostoma*) *gigantea* Sow., L.; *Cardinia* (*Pachyodon*) *Listeri* Stutch., L., and M.; *Pecten æquivalvis* Sow., M.; *Pholadomya ambigua* Sow., U., M., and L.: GASTEROPODS, *Pleurotomaria Anglica* Dfr., L.; *P. expansa* Phill., L. and M.; *Turbo heliciformis* Geol. Surv., L.; *T. subduplicatus* D'Orb., U.: CEPHALOPODS, Fig. 788, 788 *a*, *Ammonites Bucklandi* Sow., Brngt., L.;

A. planorbis Sow., L.; *A. Conybeari* Sow., L.; Fig. 787, *A. spinatus* Brug., M.; *A. heterophyllus* Sow., M. and U.; *A. radians* D'Orb., U.; *A. serpentinus* Schl., U.; *Belemnites acutus* Miller, L.; Fig. 795, *B. clavatus* Schl., L. and M.; *B. irregularis* Schl., U.; *Geoteuthis Bollensis* Mü., U. The fossil beak-like jaws of Cephalopods are called *Rhyncholites.* The last species of *Conularia* occurs in the Lias.

3. Articulates. — Crustaceans, *Eryon Barrovensis* M'Coy, L.; *Glyphea liassina* Meyer, L.; Insects, species of *Buprestids, Curculionids, Carabids, Gryllus, Ephemera, Asilus* (Dipter), etc.

4. Vertebrates. — Fishes, *Acrodus nobilis* Ag., L.; *Æchmodus angulifer* Eg., L.; *Æ. Leachii* Eg., L.; *Dapedius politus* Leach, L.; *Hybodus reticulatus* Ag., L.; Reptiles, Figs. 805–808, *Ichthyosaurus communis* Conyb., L.; *I. intermedius* Conyb., L.; *I. tenuirostris* Conyb., L.; Figs. 809, 810, *Plesiosaurus dolichodeirus* Conyb., L.; Fig. 811, *P. macrocephalus* Owen, *Dimorphodon macronyx*, L.; *Teleosaurus Chapmanni* König, L

2. *Oölytic Epoch.*

I. Lower Oölyte. — (1.) *Inferior Oölyte.* — *Anabacia hemisphærica* E. & H., *Montlivaltia trochoides* E. & H.; Fig. 770, *Prionastræa oblonga, Dysaster ringens* Ag., *Clypeus Hugi* Ag.; *Rhynchonella spinosa* Dav., *Terebratula fimbria* Sow., *T. perovalis* Sow.; *Ostrea Marshii* Sow., *O. acuminata* Sow., *Camptonectes* (*Pecten*) *lens* Sow., *Trigonia costata* Park., *Pholadomya fidicula* Sow., *Litorina ornata* Sow., *Pleurotomaria granulata* Dfr., *P. elongata* Dfr.; Fig. 789, *Ammonites Humphreysianus* Sow., *A. Parkinsoni* Sow., *A. Braikenridgii* Sow., *Nautilus lineatus* Sow., *Belemnites giganteus* Schl.

(2.) *Great Oölyte* (Bath Oölyte, including Stonesfield slate, Cornbrash and Forest Marble). — *Pecopteris diversa* Phill., *P. approximata* Phill., *Sphenopteris plumosa* Phill., *Palæozamia megaphylla* Phill., *Thuyites articulatus* Sternb., *T. divaricatus* Sternb. (all plants of Stonesfield Slate); — Fig. 769, *Montlivaltia caryophyllata* Lmx.; *Apiocrinus Parkinsoni* Schl., *A. elegans* D'Orb., *Clypeus patella* Ag.; *Terebratula digona* Sow. *Ostrea acuminata, Camptonectes lens, Pecten vagans* Sow., *Pholadomya gibbosa, Trigonia costata; Purpuroidea nodulata* Lyc., *Cylindrites acutus* L. & M.; *Ammonites discus*, Sow., *A. bullatus, A. Caprinus* Schl., *Belemnites giganteus; Libellula Westwoodii*; Fig. 813; *Megalosaurus Bucklandi* Mey., *Teleosaurus, Cetiosaurus Oxoniensis, Pterodactyls, Ramphorhynchus Bucklandi*, etc. Fig. 818, *Amphitherium Broderipii*; Fig. 819, *Phascolotherium Bucklandi.*

II. Middle or Oxford Oölyte. — (1.) *Oxford Clay* and *Kelloway Rock.* — Fig. 768, *Scyphia reticulata* (Sponge); *Anabacia orbitulites* Lmx., *Isastræa explanata* Goldf.; *Dysaster canaliculatus* Ag., *D. ovalis*, Ag. Fig. 772, *Saccocoma pectinata* Ag.; *Terebratula diphya* Bu., Fig. 780; *Ostrea Marshii, O. gregaria* Sow., *Gryphæa dilatata* Sow., *Trigonia elongata* Sow., Fig. 783, *T. clavellata* Park., Fig. 790; *Ammonites Jason* Mü., *A. coronatus* Brug., *A. Calloviensis* Sow., *Belemnites hastatus* Blv.

(2.) *Coral Limestone* (Coral Rag). — *Thecosmilia annularis* M. Edw., *Thamnastræa arachnoides* M. Edw., *Isastræa explanata* Goldf., *Stylina tubulifera* M. Edw.; Fig. 771, *Apiocrinus Roissyanus* D'Orb., *Hemicidaris intermedia* Forbes, *Cidaris coronata* Goldf., Fig. 774, *Cidaris Blumenbachii* Münst., *Pygaster patelliformis* Ag.; *Ostrea gregaria, Trigonia Bronnii* Ag., *T. costata* Park., Fig. 785, *Diceras arietinum* Lam., *Astarte elegans* Sow., *A. ovata* Smith, Fig. 784, *A. minima* Phill.; *Nerinæa fasciata*, Voltz., Fig. 786 *a, b, N. Goodhallii* Sow.; *Ammonites Altenensis, A. plicatilis* Sow. At Solenhofen, Fig. 799, *Eryon arctiformis* Br., Fig. 798, *Libellula*; Fig. 804, *Aspidorhynchus*; Fig. 817, *Archæopteryx macrura*; *Pterodactylus crassirostris* Goldf., and other species.

III. Upper Oölyte. — (1.) *Kimmeridge Clay.* — *Ostrea deltoidea* Sow., Fig. 781, *Exogyra virgula* Defr., *Trigonia muricata* Ag., *T. clavellata* Park.; *Nerinæa Gosæ* Röm., *Pterocera Oceani* Brngt.; *Ammonites decipiens* Sow., *A. rotundus* Sow., *A. biplex* Sow.; species of *Ichthyosaurus, Plesiosaurus, Pliosaurus, Teleosaurus, Megalosaurus, Goniopholis, Steneosaurus*, etc.

(2.) *Portland Oölyte.* — *Isastræa oblonga* E. & H.; *Ostrea expansa* Sow., *Trigonia gibbosa* Sow., Fig. 783, *T. clavellata, Lucina Portlandica* Sow., *Cardium dissimile*

Sow., *Mactra rostrata; Natica elegans* Sow.; *Ammonites giganteus* Sow.; *Hybodus strictus* Ag.; *Cetiosaurus longus* Owen.

7. Purbeck Beds. — *Mantellia megalophylla* Br. (Fig. 762); *Hemicidaris Purbeckensis* Forbes; *Ostrea distorta* Sow.; *Paludina carinifera* Sow.; *Cypris* (various species); *Aspidorhynchus Fisheri* Eg., *Goniopholis crassidens* Ow. (a Crocodilian); Fig. 800, *Archæoniscus Brodiei* (an Isopod Crustacean). Mammals, *Plagiaulax Becklesii, P. minor, Spalacotherium Brodiei* Owen.

3. *Wealden Epoch.*

1. Plants.— Conifers closely allied to *Araucaria, Abies, Cupressus, Juniperus;* Cycads; trees allied to *Dracæna, Yucca,* and *Bromelia; Ferns,* the *Sphenopteris Mantelli* Brngt., *Clathraria Lyellii* Mant., etc.; the delicate *Charæ* of rivulets.

Figs. 820, 821.

Mollusks. — Fig. 820, Unio Valdensis; 821 Viviparus (Paludina) fluviorum.

2. Mollusks. — Fresh-water species in large numbers, especially of the genera *Cyrena, Planorbis, Limnæa, Unio,* and *Paludina.* Fig. 820, *Unio Valdensis* Mant.; 821, *Viviparus* (*Paludina*) *fluviorum* Sow., also *Melania attenuata* Sow., *Neritina Fittoni* Mant.

3. Articulates. — Ostracoids, related to *Cypris,* etc., very abundant in some layers. Insects of thirty or forty families, including *Coleopters, Orthopters, Neuropters, Hemipters,* and *Dipters,* or Beetles, Crickets, Dragon-flies, Cicadæ, May-flies, etc.

4. Vertebrates. — *Fishes,* of the orders of *Ganoids* and *Selachians,* in all thirty or forty species, including *Lepidotus Fittoni* Ag., *Pycnodus Mantelli* Ag., *Hybodus subcarinatus* Ag. *Reptiles.* — Enaliosaurs, of the genera *Ichthyosaurus* and *Plesiosaurus;* Dinosaurs, of the genera *Iguanodon, Hylæosaurus, Megalosaurus, Regnosaurus;* Fig. 814, tooth of the *Iguanodon;* Crocodilians with *biconcave* vertebræ, of the genera *Suchosaurus Goniopholis, Pœcilopleuron,* etc.; with *convexo-concave* vertebræ, of the genus *Cetiosaurus,* and also the first of the *concavo-convex,* or procœlian, in species of the modern genus *Crocodilus;* Pterodactyls; Turtles, as the *Tretosternum punctatum* Owen (*Trionyx Bakewelli* Mantell), etc.

3. General Observations.

Geography. — From the outcropping of the Jurassic beds along the Black Hills and the flanks of the Rocky Mountains, Hayden & Meek have inferred with good reason that these rocks probably underlie the wide-spread Cretaceous strata of the eastern slope of the Rocky Mountains; and, as the elevation of the Rocky chain above the ocean was not completed until long after the close of the Cretaceous period

(although begun long before, as regards some of its subordinate ridges), we may infer that the condition mentioned as characteristic of the Triassic period — a shallow submergence beneath an inland sea (p. 423) — was followed in the Jurassic period by a somewhat deeper submergence, or at least that the waters communicated directly with the ocean, so that marine life once more covered the Rocky Mountain region, from Kansas westward beyond the summit of the chain, even to the Pacific, and that, in these shallow seas, limestones were forming again, as in the later half of the Carboniferous age.

The absence of sea-shore Jurassic beds from the Atlantic border leads to the same conclusions with regard to the coast, in the Jurassic period, that were deduced for the Triassic (p. 422).

The Jurassic period commenced in England with the marine deposits of the Lias. Through the era of the Oölite, the alternations were very numerous, indicating oscillations between clear seas and shallow water or half-emerging land, in the course of which there were coral reefs in England and Europe. The evidences of shallow water and emerging flats increase toward the close of the period, dry-land intervals begin to predominate over the marine, and finally the rock-formations are partly those of lakes and estuaries. The history in Europe in part runs parallel with this, although with many local peculiarities.

The position of the Jurassic beds across England, on the east of the older parts of the island, and their continuation over parts of northern France, correspond with the view that they were formed on the borders of a German Ocean basin. This is well shown, as regards England, on the map on p. 344.

While, in both Europe and America, the Triassic period was, in the main, one of great marine marshes and shallow waters, the Jurassic was in both as generally characterized by moderately deep waters and open continental seas.

Life. — It is evident from the review that Conifers, Tree Ferns, and Cycads gave character to the forests of the Jurassic world; while Reptiles and Marsupials were the dominant types of the fauna. Reptiles were preëminent in each of the three elements, — in place of whales in the *water*, of beasts of prey and herbivores on the *land*, and of birds in the *air*.

The multitudes of Reptilian and other remains, entombed in the Stonesfield slate, the Wealden, and the beds at Solenhofen, do not indicate an excess of population about these spots. They point out only the places where the conditions were favorable for the preservation of such relics; they in fact prove that the land was everywhere covered with foliage, and swarming with life.

The dirt-bed of Portland, abounding in Mammalian remains, and yet only five inches thick, shows strikingly what we ought to find in the Coal formation, with its many scores of dirt-beds of far greater thickness, if Mammals were then living.

Climate. — The existence of *Belemnites paxillosus* and *Ammonites biplex* (or closely-allied species) in the Arctic, in the Andes of South America, and in Europe, indicates a remarkable uniformity of climate over the globe in the Jurassic period. This has been made still more striking, by the discovery, by Sir Edward Belcher, of the remains of an *Ichthyosaur* on Exmouth Island, in 77° 16′ N. and 96° W., 570 feet above the sea; and also by that of Captain Sherard Osborn, of two bones of a species related to the *Teleosaurs*, on Bathurst Island, in 76° 22′ N. and 104° W. No facts are yet ascertained, connected with the geographical distribution of species, that sustain the idea of a diversity of zones approaching in amount the present. The climate of the Arctic regions in the Jurassic was probably at least warm-temperate.

The existence of coral reefs in England, in the Oölitic era, consisting of corals of the same grand groups with those of the existing tropics, shows that the Coral-sea limit — marked off by the water-isothermal of 68° F. as the average of the coldest winter month (see page 41 and chart of the world) — extended north of part of the British seas, or 30° (over 3,000 miles in distance) farther north than its present most extra-tropical position just outside of the Bermudas. The Gulf Stream was probably the cause of this long northward stretch of tropical waters. The Oölytic isocryme of 68° F., accordingly, would have had nearly the position of the present line of 44° F., but with a little less northing and more leaning to the eastward. The whole ocean was enough warmer to allow this ocean current to bear the heat required for corals, as far north as northern England.

4. Disturbances Closing the Jurassic Period.

The igneous eruptions which made the trap ridges and trap dikes that intersect the Connecticut River valley and other Triassic regions, from Nova Scotia to South Carolina (described on page 417), may have taken place at the close of the Jurassic period. All that the facts definitely teach is that the outbreaks were subsequent, in part if not wholly, to the deposition of the accompanying sandstone beds, and anterior to the Cretaceous period.

On the Pacific border, the evidences of disturbance, at this epoch, are more positive; and the results were of a grander character. The Sierra Nevada, according to the facts brought out by Professor Whitney, dates its existence from this time. As has been stated, Triassic and

Jurassic rocks enter into its constitution (their fossils being found along a distance of 250 miles, on the western side), while the Cretaceous beds lie unconformably on the flanks of the mountains. The chain, in the language of Professor Brewer (in a review of Whitney's Geological Report), "consists essentially of an immense core of granite, flanked on either side by metamorphic slates;" "the culminating points in the *southern* portion [Mt. Whitney, the highest among them, about 15,000 feet above the sea] are of granite; in the *central*, of slates; and in the *northern*, of volcanic rocks" [of later date]. Yosemite Valley lies in the broad central granite belt of the southern part. Again he says, "In passing along the foot-hills of the chain, at its western base, we find, at numerous points, the marine Tertiary, or Cretaceous, or both, resting in a horizontal position on the upturned edges of the metamorphic rocks of the auriferous series." "These horizontal strata occur at intervals for over 400 miles, along the western base of the chain;" "to the north, the Cretaceous predominating, and to the south, the Tertiary."

As the quartz veins intersect the Triassic and Jurassic (now metamorphic) slates, they also are part of the results of the great upturn and uplift. They show where the leaves of the slates were opened or broken, and where great fractures were made through the deep formations, in the course of the upturning; and where the heat, developed by the upturning, turned all water or moisture present into hot alkaline solutions of silica; and these solutions, passing into the cavities and all opened spaces, deposited the silica and so filled them with quartz. Thus the auriferous quartz "reefs" or veins were made; for the gold and all associated metallic ores were carried in at the same time, the hot waters gathering them far and wide from the slates adjoining. Some of the auriferous quartz veins thus made are of extraordinary size. "In the Pine Tree and Josephine mines, near the north end of the [Mariposa] estate, the average breadth of the quartz is fully twelve feet; and in places it expands to forty feet."

While the Sierra Nevada was in process of formation on the eastern borders of California, the Wahsatch, another high range parallel with it, and the Uintah, a transverse range, were in progress, according to the observations of Clarence King, over a region east of the meridian of Great Salt Lake; and still others, called the Humboldt ranges, over the plateau between the Sierra and the Wahsatch.

3. CRETACEOUS PERIOD (18).

The Cretaceous period is the closing era of the Reptilian Age. It is remarkable for the number of genera of Mollusks and Reptiles

which end with it, and also for the appearance, during its progress, of the modern types of plants.

The name CRETACEOUS is from the Latin *creta, chalk.* The Chalk of England and Europe is one of the rocks of the period.

1. AMERICAN.

Epochs. — 1. EPOCH of the Earlier Cretaceous; 2. EPOCH of the Later Cretaceous.

I. Rocks: kinds and distribution.

The Cretaceous beds occur (1) at intervals along the *Atlantic Border* south of New York, from New Jersey to South Carolina; (2) extensively over the States along the *Gulf Border*, thence bending northward along the Mississippi valley, nearly or quite to the mouth of the Ohio, over what was then a great Mississippi bay; (3) through a large part of the *Western Interior* region, over the slopes of the Rocky Mountains, from Texas northward to the head-waters of the Missouri, and westward through Dakota, Wyoming, Utah, and Colorado territories; farther west, along some parts of the valley of the Colorado River, but not over the plateau between the Sierra Nevada and the Wahsatch Range; (4) along the *Pacific Border*, in the Coast ranges west of the Sierra Nevada; (5) in British America, on the Saskatchewan and Assiniboine; also (6) on the Arctic ocean, near the mouth of the Mackenzie, and in North Greenland. On the *Atlantic Border*, they are unknown north of Cape Cod.

The formation has its greatest thickness in the Rocky Mountains. The accepted subdivisions for the Rocky Mountain region are, beginning below, (1) the *Dakota* group, which has often a conglomerate bed as its base; (2) the *Colorado* group; (3) the *Fox Hills* group; the maximum thickness of the whole, in the Wahsatch Range, 8,000 or 9,000 feet. The beds are marine, but some coal beds are included in the upper portion. Above No. 3 there is a gradual passage into a group of brackish water strata 4,000 to 5,000 feet thick, including many coal-beds, which is called the *Laramie* group, or the "Lignitic" formation. It is allied to the Cretaceous in its Dinosaurs, and to the Tertiary in its fossil plants, and is thus intermediate in its life between the Cretaceous and Tertiary. It is placed beyond in the Tertiary (p. 490), but is as rightly made No. 4 of the Cretaceous, as done by many geologists.

On the map, p. 144, the Cretaceous areas are indicated by broken lines running obliquely from the right above to the left below: one area crosses New Jersey; other outcrops on the Atlantic Border are indicated by the lettering *Cr;* an extensive area covers the Gulf States; and another, the region west of the Mississippi.

The rocks comprise beds of sand, marlyte, clay, loosely-aggregated shell limestone, or "rotten limestone," and compact limestone. They include in North America no chalk, excepting in western Kansas, where, 350 miles west of Kansas City, a large bed exists. The Cretaceous limestones in Texas are firm and compact; and some beds contain hornstone distributed through them, like the flint through the Chalk of England.

The sandy layers predominate. They are of various colors, — white, gray, reddish, dark green; and, though sometimes solid, they are often so loose that they may be rubbed to pieces in the hand, or worked out by a pick and shovel.

The dark-green sandy variety constitutes extensive layers, and goes by the name of *Green-sand;* and, as it is valuable for fertilizing purposes, and is extensively dug for this object, it is called *marl* in New Jersey and elsewhere. This Green-sand owes its peculiarities to a green silicate of iron and potash, which forms the bulk of it, and sometimes even 90 per cent., the rest being ordinary sand. There is a trace of phosphate of lime, evidently derived from animal remains, — as animal membranes and shells contain a small percentage of phosphates. Its value in agriculture is due to the potash and phosphates.

Fossil shells are abundant in many of the arenaceous and marly beds; and in some they lie packed together in great numbers, as if the sweepings of a beach, or the accumulations of a growing bed in shallow waters, sometimes cemented together, but generally loose, so as to be easily picked out by the fingers.

The most northern outcrop of the Cretaceous observed on the Atlantic coast is in New Jersey, just south of Sandy Hook. Mather suggested, in his "New York Geological Report," that the formation underlies the sands of Long Island through its whole length, on the ground that fossil shells and lignite have been found in digging wells, and other excavations; but, as he had seen none of the shells, the evidence thus far published is as good for the existence of Tertiary beds as for Cretaceous.

The inner limit of the Cretaceous formation, on the Atlantic border (see map, p. 144), follows a line across New Jersey, from Staten Island to the head of Delaware Bay; across Delaware to the Chesapeake; across Maryland, between Annapolis and Baltimore, southwest into Virginia. The formation occurs at Elizabeth on Cape Fear River, in North Carolina, and sparingly in South Carolina. But, more to the westward, at Macon, Georgia, commences the large Southern Cretaceous region, which is continued into the Mississippi basin, and whose inner outline passes by Columbus in Georgia, Montgomery in Alabama, and then bends northward over northeastern Mississippi across Tennessee, just west of the Tennessee River, toward the mouth of the Ohio; it outcrops southward on the west side of the Mississippi over eastern Arkansas, spreading at the same time westward, south of Little Rock and Fort Washita. Not far from the last point, the Cretaceous area expands southward over part of Texas; also northward, covering part of the western border of Iowa and Minnesota, and continuing on in the same direction, beyond the northern boundary of the United States, into British America. It also spreads over a large part of the eastern slope and the summit region of the Rocky Mountains, as already mentioned. West of the summit, it extends over much of the valley of the Colorado, to the meridian of 113° W. In California, the Cre-

taceous occurs in the Coast ranges, becoming most prominent to the north of San Francisco, and along the foot-hills of the Sierra Nevada, from Placer County to Shasta; and in Oregon, east of the Cascade range (Marsh).

As the Cretaceous formation is very fully represented in the region of the Upper Missouri, a detailed section of it, by Meek & Hayden, is here given, beginning below, the Laramie group excluded : —

1. Dakota Group. — Yellowish, reddish, and whitish sandstones and clays, with lignite and fossil Angiospermous leaves: thickness, 400 feet. Location, near Dakota, and reaching southward into northeastern Kansas. This division may require to be united with No. 2 (M. & H.).
2. *Benton Group.* — Gray laminated clays, with some limestone: thickness, 800 feet. Location, near Fort Benton, on the Upper Missouri, also below the Great Bend; eastern slope of the Rocky Mountains.
3. *Niobrara Group.* — Grayish calcareous marl: thickness, 200 feet. Location, Bluffs on the Missouri, below the Great Bend, etc.
4. *Pierre Group.* — Plastic clays: thickness, 700 feet; — middle part barren of fossils. Located on the Missouri, near Great Bend, about Fort Pierre and out to the Bad Lands, on Sage Creek, Cheyenne River, White River above the Bad Lands.
5. Fox-Hills Group. — Gray, ferruginous, and yellowish sandstones and arenaceous clays: thickness, 500 feet. Location, Fox Hills, near Moreau River, above Fort Pierre near Long Lake, and along the base of Big Horn Mountains.

Nos. 2, 3, and 4, correspond collectively to the Colorado group (p. 454).

No. 1 occurs at different points in New Mexico (Newberry). No. 2, on the north branch of the Saskatchewan, west of Fort à la Corne, lat. 54° N.; in New Mexico (Meek). No. 3, over the region from Kansas through Arkansas to Texas. in the Pyramid Mountain. No. 4, in British America, on the Saskatchewan and Assiniboine; on Vancouver Island; Sucia Islands, in the Gulf of Georgia No. 5, at Deer Creek, on the North Platte, and not identified south of this. (Meek & Hayden.)

King gives for the Dakota group, in the Uinta Range, a thickness of 500 feet, for the Colorado group, where thickest, 2,000 feet; the Fox Hills group, 3,000 to 4,000 feet. The conglomerate at the base of the Dakota separates it from the underlying Jurassic beds. The fossil plants of the Cretaceous in the Rocky Mountains come from the lower part of the Dakota group. At the very base of the group in the Uinta region there is an excellent coal-bed, which does not occur to the eastward.

In Mississippi, Hilgard has made out the following subdivisions: —

1. (Lowest) *Eutaw group* (Coffee group of Safford), consisting of clays, with usually some sand beds above, and containing beds of lignite and rarely other fossils, the thickness 300 to 400 feet.

2. *Rotten-Limestone* group, not less than 1,200 feet thick, made up of soft, chalky, white limestones, underlying the prairies, and containing *Placuna scabra* Mort., *Neithea Mortoni* Gabb, *Gryphæa convexa* Mort., *G. mutabilis* Mort., *G. Pitcheri* Mort., *Ostrea falcata* Mort., *Rudistes*, *Mosasaurus*, and including the "Tombigby Sand," in which occur many Selachian relics and the gigantic *Ammonites Mississippiensis*.

3. The *Ripley group*, hard white limestones, often glauconitic and sandy, underlaid by black or blue micaceous marlytes, 300 to 350 feet thick, and containing *Cucullæa capax* Con., *Gervillia ensiformis* Con., *Baculites Spillmani* Con., *Scaphites Conradi* D'Orb., *Ammonites placenta* Dekay, etc., forming the Pontotoc ridge in Mississippi, the Chunnenugga ridge in southeastern Alabama, and occurring also at Eufaula, Ala. 1 is Hayden's No. 1; 2, his No. 4; and 3, his No. 5 (Hilgard, Am. J. Sci., III. ii. 392).

In Tennessee, there are the Coffee Sand, 200 feet thick; the Green-sand or Shell bed (Rotten Limestone), 200 to 350 feet; the Ripley group, 400 to 500 feet thick, consisting mostly of stratified sands.

In Alabama, the thickness of the Cretaceous is 2,000 feet, 900 to 1,100 of it the Rotten Limestone.

In Texas, the beds consist mainly of compact limestone, and the larger part are of the *Later* Cretaceous. Shumard gives the following subdivisions: Marly clay, 150 feet

overlaid by arenaceous beds, 80 feet (Nos. 1 and 2). (*a.*) Caprotina limestone, containing *Orbitolina Texana*, etc., 55 feet; (*b.*) Blue marl, 50 feet; (*c.*) Washita limestone, 100 to 120 feet (No. 3). (*d.*) Austin limestone, 100 to 120 feet (No. 4). (*e.*) Comanche Peak Group, 300 to 400 feet; (*f.*) Caprina limestone, 60 feet.

In the New Jersey Cretaceous, the beds and their relations to those of Nebraska are thus stated by Meek & Hayden, from the observations of G. H. Cook: —

1. Earlier Cretaceous (?). — No. 1 (?) Bluish and gray clays, micaceous sand, with fossil wood and Angiospermous leaves: thickness, 130 feet or more.
2. Later Cretaceous. — Nos. 4 and 5. (*a.*) Dark clays (130 feet), overlaid by (*b.*) the *first* bed of *Green-sand*, 50 feet thick. — No. 5. (*a.*) Sand-beds colored by iron, 60 to 70 feet; (*b.*) second bed of *Green-sand*, 45 to 50 feet; (*c.*) yellow limestone. The whole thickness has been stated at 400 to 500 feet.

In California, the coast ranges, according to Whitney, "are to a large extent made up of Cretaceous rocks, usually somewhat metamorphic, and often highly so." Many of the altered beds are jaspery, and some are serpentine. They occur also on the flanks of the Sierra Nevada, in Northern California. The beds referred to the Cretaceous belong, as shown by Gabb's study of the fossils, to two or three groups: (1) the *Shasta Group*, or older Cretaceous, which includes beds occurring in mountains west and northwest of Sacramento valley, on Cottonwood Creek, etc.; also in Mitchell Cañon, north side of Mount Diablo: (2) the *Chico group*, or Middle Cretaceous, the most extensive in California, represented in Shasta and Butte counties, and in the foot hills of the Sierra Nevada as far south as Folsom, and also on the eastern face of the coast ranges bordering the Sacramento valley; and including at top the Martinez group on the north flank of Mount Diablo; also in Oregon, at Jacksonville, etc., and on Vancouver's Island, the coal-bearing strata of that island being referred to it. The third group — the *Tejon group* — occurs about Fort Tejon and Martinez, and from there along the Coast ranges to Marsh's, fifteen miles east of Mount Diablo; also on the eastern face of the same range, to New Idria, etc., and near Round Valley in Mendocino County, it being the only *coal-producing* formation in California.

The reference to the Cretaceous of the whole of the Coal-bearing or "Lignitic" group, of Wyoming, Utah, Colorado, and the eastern slope of the Rocky Mountains, is sustained by the occurrence in them of some Cretaceous types of Mollusks and Reptiles, as species of *Inoceramus*, *Anchura*, *Gyrodes*, and *Dinosaurs*. In each of the territories just mentioned, occur specimens of *I. problematicus*, at different levels in the Coal formation; near Bear River, Wyoming, a bed is full of good specimens; at Coalville, specimens occur over one of the lowest beds of coal, and another species of *Inoceramus* in a sandstone thousands of feet higher; and none of the specimens, mostly casts, bear any evidence of transfer from an older formation (Meek). Again, Marsh found, over the coal series, six miles from Green River, near Brush Creek, in Utah, a layer full of *Ostrea congesta* Con., a typical Cretaceous fossil, and above this a crinoid perhaps related to the Cretaceous *Marsupites*, and also scales of a *Beryx*, a genus of Cretaceous fishes; and in shales, below the coal bed, remains of Turtles of Cretaceous types, and teeth "resembling those of a *Megalosaurus*." Again, remains of various *Dinosaurs* have been found in the coal series of Black Butte Station, on Bitter Creek, Wyoming, and in other parts of the Laramie group.

On the other hand, the Mollusks of the Rocky Mountain coal formation, with the exception of the *Inocerami* and species of *Anchura* and *Gyrodes*, are stated by Meek to be decidely Eocene Tertiary in character; so much so that, if the *Inocerami* were absent, the Tertiary character would not be doubted. Further, the fossil leaves, which are of many kinds, are, according to Lesquereux, distinctively Eocene, or at least Tertiary, types. But greater weight is given, with reason, to the vertebrate fossils as marks of age than to plants, and hence the weight of evidence would thus be in favor of their Cretaceous rather than Tertiary age.

The beds referred to the Laramie group include the Lignitic series east of the Rocky Mountains in Colorado, the Bitter Creek series of Southern Wyoming, and of adjacent parts in northwestern Colorado, the Evanston coal series and Bear River beds, and their equivalents in Wyoming and Utah, and the Judith River and Fort Union beds of the

Upper Missouri region. The group extends from Southern Colorado northward beyond the United States boundary, and hence has a length exceeding 1,000 miles, with an average width of 500 miles (C. A. White). The Wahsatch range is its western boundary. In their sandy nature the beds closely resemble those of the Fox Hills group.

It is also possible that the *Tejon group*, the coal-bearing group of California, is an equivalent of the Wyoming coal series or Laramie group. Gabb states that a species of *Ammonites* extends through the group to the very top, and affords strong evidence of its Cretaceous age; and this is made stronger by the occurrence also of three or four species of the Chico group in the Tejon group, *e. g.*, *Mactra* (*Cymbophora*) *Ashburnerii* Gabb., *Nucula truncata* Gabb., *Avicula pellucida* Gabb. To show the Tertiary aspect of the shells, the genera are enumerated on page 508. Conrad referred the California beds to the Eocene.

The Vancouver Island Cretaceous contains workable beds of coal, and has afforded *Inocerami*, *Trigoniæ*, *Ammonites*, *Baculites*, *Belemnites*, and other Cretaceous fossils.

Economical Products.

Mines of *Cinnabar*, the chief ore of quicksilver, occur at various points in the metamorphic Cretaceous rocks of the Coast ranges of California. The usual associated rocks are serpentine and argillaceous and siliceous slates. The most productive region is that of New Almaden, fifty miles south-southwest of San Francisco. It is worked also at New Idria, in Fresno County, at the Reddington mine in Lake County, and at some other points.

The Coal-beds, whether Cretaceous or Tertiary, are of great value to the country. They are described under the Tertiary.

Gold is found sparingly in the metamorphic Cretaceous of California, but has not repaid working. Copper also occurs in many localities, but not in workable veins. Chromic iron is found in the serpentine of California, but not in a condition to repay mining.

The *Green Sand* has already been mentioned as a valuable fertilizer. The green grains (called also *Glauconite*) consist of about 50 per cent. of silica, 20 to 25 protoxyd of iron, 8 to 12 potash and soda (mostly potash), and 7 to 10 water, with also a trace of phosphate of lime. For analyses, see author's "Treatise on Mineralogy."

II. Life.

1. *Plants.*

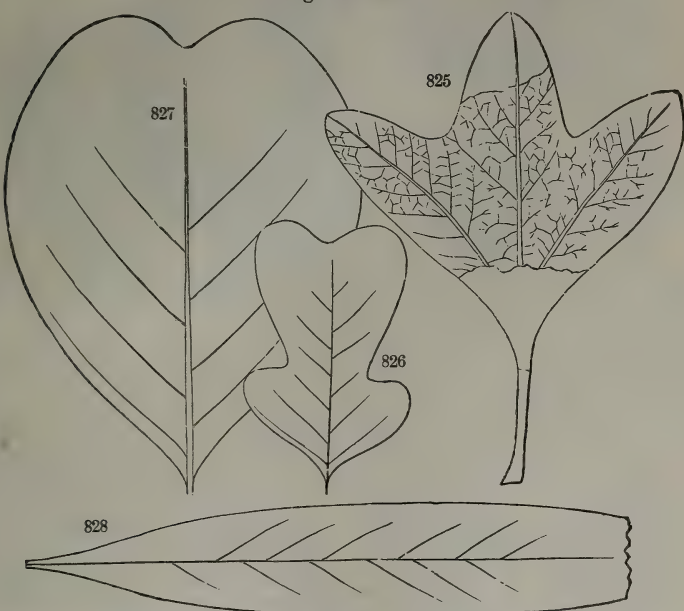
With the opening of the Cretaceous period, we find indicated in the rocks a great change in the vegetation of the continent. The Cycads of the Triassic and Jurassic still existed, but they were accompanied by the *first yet known of the great modern group of Angiosperms*, — the class which includes the Oak, Maple, Willow, and the ordinary fruit trees of temperate regions, — in fact, all plants that have a bark, excepting the Conifers and Cycads. More than one hundred species have been collected; and half of them were allied to trees of our own forests — the *Sassafras* (Fig. 825), *Tulip Tree* (Fig. 826), *Plane* (or

Sycamore), *Hickory*, *Willow* (Fig. 828), *Oak*, *Poplar*, *Maple*, *Beech*, *Fig*, or the genera *Sassafras*, *Liriodendron*, *Platanus*, *Juglans*, *Salix*, *Quercus*, *Populites*, *Acer*, *Fagus*, *Ficus*. Leaves of Sassafras, Tulip-tree, and Willow are common. There were also species of Redwood (*Sequoia*), the genus to which the "Big Trees" of California belong. There were also the *first of the Palms*. Fossil palm-leaves, of the genus *Sabal*, are met with on Vancouver's Island, in deposits which have been pronounced Cretaceous.

Coccoliths, calcareous disks less than a hundredth of an inch in diameter (p. 135), which are now common over the bottom of the deep oceans, contributed to the Cretaceous limestones, and are abundant in the Cretaceous of the east slope of the Rocky Mountains.

Fig. 825, *Sassafras Cretaceum* Newb., from the Dakota group, along with the three following (Meek & Hayden); Fig. 826, *Liriodendron Meekii* Heer; Fig. 827, *Legumi-*

Figs. 825–828.



ANGIOSPERMS (OR DICOTYLEDONS). — Fig. 825. Sassafras Cretaceum; 826, Liriodendron Meekii; 827, Leguminosites Marcouanus; 828, Salix Meekii.

nosites Marcouanus Heer; Fig. 828, *Salix Meekii* Newb. Large stumps of Cycads have been found in Maryland, near Baltimore; one is twelve inches in diameter and fifteen high. (P. T. Tyson).

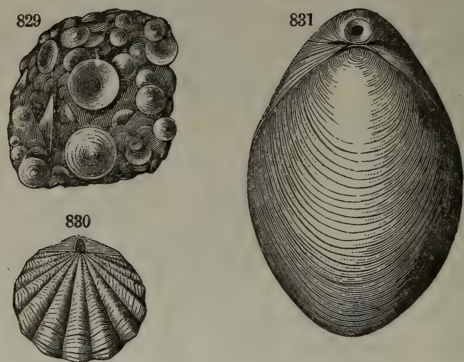
The Cretaceous species of *Platanus* are mostly analogous to *P. aceroides*. Other species from Kansas or Nebraska, *Acer obtusilobum* Lsqx., *Sequoia Reichenbachi* Heer, *Sequoia formosa* Lsqx., *Liquidambar integrifolius* Lsqx., *Populites fagifolia* Lsqx., *Ficus*

Sternbergii Lsqx., *Sassafras Mudgii* Lsqx., *S. mirabilis* Lsqx., *S. obtusus* Lsqx., *S. recurvatus* Lsqx., *Laurophyllum reticulatum* Lsqx., *Platanus Heerii* Lsqx., *Pterospermites* (*Credneria*) *Sternbergii* Lsqx., *Pt. Haydenii* Lsqx., *Pt. rugosus* Lsqx., *Salix proteifolia* Lsqx., *Betula Beatriciana* Lsqx., *Fagus polycladus* Lsqx., *Quercus primordialis* Lsqx., *Magnolia tenuifolia* Lsqx., *Pterophyllum Haydenii* Lsqx. (a Cycad).

2. *Animals.*

Among Protozoans, the group of Rhizopods had a special importance in the Cretaceous period. Their shells, *foraminifers*, are abundant in many of the beds, in New Jersey and other Cretaceous regions of North America, though less so than in the chalk beds of Europe.

Figs. 829–831.



RHIZOPOD. — Fig. 829, Orbitolina Texana. BRACHIOPODS. — Fig. 830, Terebratulina plicata; 831, Terebratula Harlani.

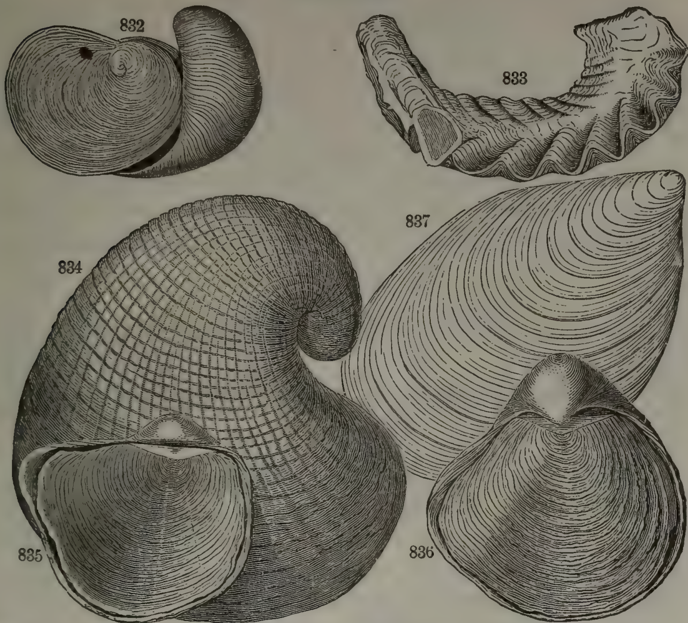
In one genus, *Orbitolina*, the species are disk-shaped (Fig. 829), and closely resemble in form some of the *Nummulites.* Sponges also are common fossils, although little known thus far in America.

Under the sub-kingdom of Mollusks, the most common Brachiopods are of the Terebratula family (Figs. 830, 831). The more characteristic genera of Lamellibranchs were the three of the Oyster family, *Ostrea* (Fig. 833), *Gryphæa* (Figs. 835, 836), and *Exogyra* (Fig. 834) (species of which occurred in the Jurassic period, but were more common and larger in the Cretaceous), and *Inoceramus* (Fig. 837), a genus related to *Avicula*, some species of which are of great size, and have the surface in undulations.

Another group characteristic of the Chalk period, and, moreover, not known after it, is that of the *Rudistes* (Figs. 862–866). It includes the genera *Hippurites*, *Radiolites*, *Sphærulites*, and a few others. *Hippurites* has a long tapering form (Fig. 862), somewhat like a nearly straight but rude horn, with a lid on the top, the lid being the upper valve and the conical portion the lower. Within, there is a

subcylindrical, tapering cavity, having one or more projecting ridges on the sides, running the whole length. Some foreign Cretaceous

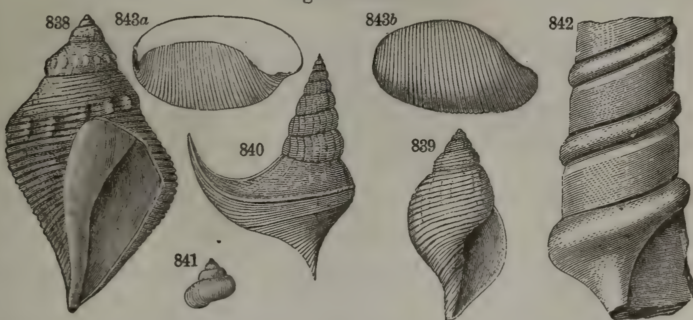
Figs. 832-837.



CONCHIFERS. — Fig. 832, Exogyra arietina; 833, Ostrea larva; 834, Exogyra costata; 835, Gryphæa vesicularis; 836, G. Pitcheri; 837, Inoceramus problematicus.

species are figured on page 462; Fig. 862 *a* shows the interior of one: there are two prominent ridges, but one is only partly free in the in-

Figs. 838-843.



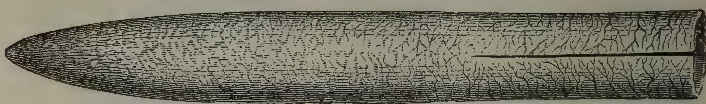
GASTEROPODS. — Fig. 838, Pyrifusus Newberryi; 839, Fasciolaria buccinoides; 840, Anchura (Drepanocheilus) Americana; 841, Margarita Nebrascensis; 842, Nerinæa Texana; 843 *a*, *b*, Bulla speciosa.

terior space. The other genera have a similar anomalous character, but differ in the interior. Fig. 863 represents the lid or upper valve of a *Radiolites*, showing the projections below (*b*, *c*), to which the muscles closing the lid are attached; and Fig. 864 is the same in *Sphærulites*. The Rudistes are supposed to be related to *Chama* among the Dimyary Mollusks.

Some of the Gasteropods are represented in Figs. 838 to 843. Fig. 842 is a *Nerinæa*, a shell having a ribbed interior, as shown on page 439. The genus began in the Jurassic, and ends with the Cretaceous.

Of Cephalopods, there were numerous *Belemnites* (Fig. 844) and *Ammonites* (Fig. 845). One of the most common of the New Jersey *Belemnites* is represented in Fig. 844. Some of the Ammonites from

Fig. 844.



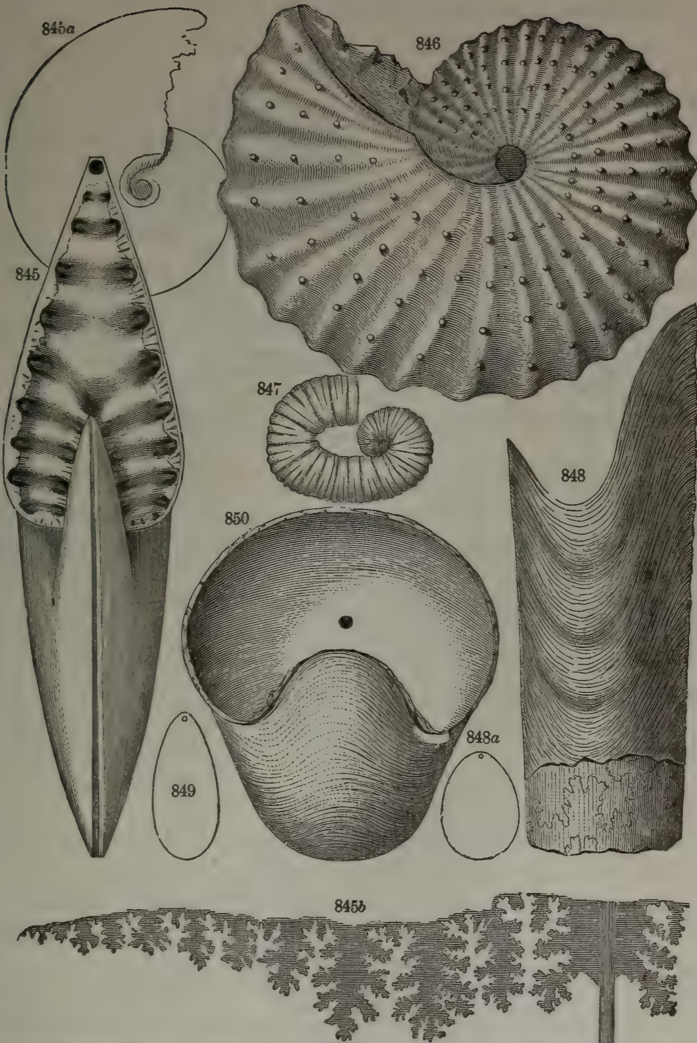
CEPHALOPOD. — Belemnitella mucronata.

beyond the Mississippi are over three feet in diameter There was also a multiplication of other genera of the Ammonite family, the shells of which are like Ammonites more or less uncoiled; as *Scaphites* (Figs. 846, 847), from *scapha, a boat; Crioceras*, p. 473, from κριός, *a ram's horn : Ancyloceras*, from ἀγκύλη, *a hook or handle ; Hamites*, from *hamus, a hook; Toxoceras*, from τόξον, *a bow ; Baculites* (Fig. 848), from *baculum, a walking-stick. Turrilites* (Fig. 871). a form unlike other *Ammonitids* in being a turreted spiral; another, opened spiral, called *Helicoceras*. Figures of several of these forms are given on p. 473. Among these genera, *Ammonites*, *Scaphites*, *Ancyloceras*, *Hamites*, *Ptychoceras*, *Baculites*, *Turrilites*, and *Helicoceras* have been found in American Cretaceous rocks. *Baculites ovatus* (Fig. 848) attained a length of a foot or more, and a diameter of two and a half inches; and *Scaphites Conradi* (Fig. 846), a length of six inches.

Among *Vertebrates*, there was the first appearance of several prominent modern groups, marking grand steps of progress in the life of the world.

Among Fishes, *Sharks* and *Ganoids* continued to be common, as before. In addition, there were large numbers of the Common or *Osseous fishes*, or *Teliosts*, the tribe which includes the larger part of modern fishes and nearly all edible species. The Cestraciont Sharks still continue; and the bony pavement pieces of the mouth are not rare fossils. Two views of one from New Jersey are given in Figs. 853, 853 *a*. The Sharks were largely of the modern type of *Squalo-*

Fig. 845-850.



CEPHALOPODS. — Figs. 845, 845 *a*, 845 *b*, Ammonites placenta; 846, Scaphites Conradi; 847, S. larvæformis; 848, 848 *a*, Baculites ovatus; 849, Section of B. compressus, reduced; 850, Nautilus Dekayi.

donts, which have teeth with sharp cutting edges, besides other peculiarities. A tooth of one large species is represented in Fig. 852.

Several species of Teliosts have been described by Cope, from the

Upper Cretaceous of Kansas, related to the Salmon and Saury-pike; and a *Beryx*, from the Green-sand of New Jersey.

Figs. 852–853.

Squalodont Selachian. — Fig. 852, Otodus appendiculatus. Cestraciont Selachian. — Figs. 853, 853 *a*, Ptychodus Mortoni.

Reptiles were exceedingly numerous, and many of them of enormous size. There were *Enaliosaurs*, or *swimming Reptiles*, related to the long-necked Plesiosaur, fifteen to forty feet long; *snake-like Reptiles*, having short paddles, called *Mosasaurs*, ten to seventy feet long; *carnivorous* and *herbivorous Dinosaurs*, some of great size, that walked as bipeds, like those of the Triassic; others related to the Iguanodon, somewhat like Megatheria in their habits; *Crocodilians*, some of old Teleosaurian type, having biconcave vertebræ, and others related to the Gavial of the Ganges; *flying reptiles*, or *Pterosaurs*, of various sizes, besides *Turtles*, large and small. The variety of Reptilian species was even greater than in the Jurassic period, and more diverse in some respects from that of later time.

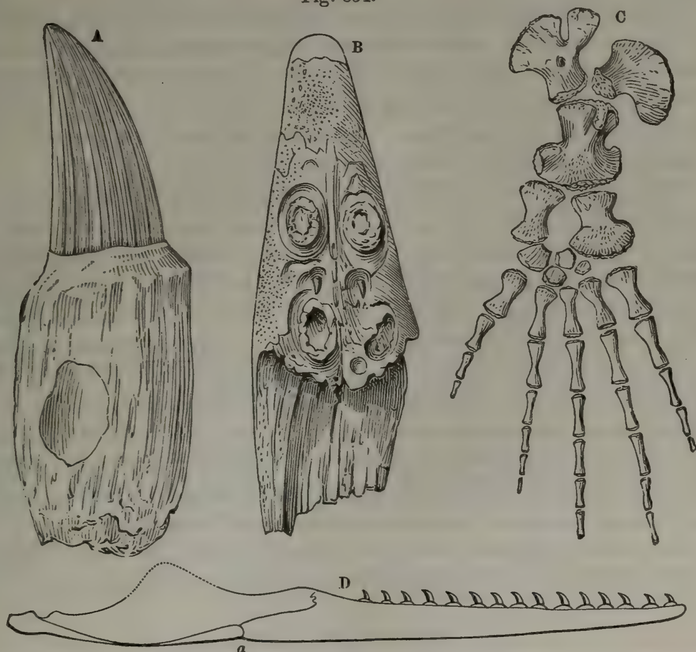
Among the *Dinosaurs*, the *Hadrosaur* closely resembled the *Iguanodon*, and was full twenty-eight feet in length. The *Lælaps*, twenty-four feet long, was carnivorous, and differed little, if at all, from the *Megalosaur*, having longer limbs behind than before; and, as Cope states, it probably was able to stand erect on its hind feet, carrying its head at least twelve feet high. Another, the *Ornithotarsus* of Cope, having the habit of *Lælaps*, is supposed to have been thirty-five feet in length. North America abounded in Dinosaurs, during the era of the Connecticut River sandstone — the Triassico-Jurassic; and it appears also to have vastly exceeded Europe in the number of its Cretaceous Dinosaurs.

Among *Enaliosaurs*, or Sea-saurians, one, called *Discosaur* by Leidy (*Elasmosaurus platyurus* Cope), was fifty feet long, and had a neck of over sixty vertebræ, measuring twenty-two feet in length. It

was carnivorous; and the teeth and scales of fishes have been found with the bones, where the stomach once lay.

Mosasaurs, great swimming snake-like reptiles, were literally the sea-serpents of the era. Remains of over forty American Cretaceous species of this tribe have been found — about fifteen in New Jersey, six or more in the Gulf beds, and over twenty in Kansas; and one of them, at least, *Mosasaurus princeps*, was seventy-five to eighty feet long. The first one known was found in Europe, near the river

Fig. 854.



MOSASAURIDS. — Fig. 854 A, Tooth of Mosasaurus princeps (× ½); B, snout of Tylosaurus micromus, showing bases of four teeth (× ¼); C, right paddle of Lestosaurus simus (× $\frac{1}{12}$); D, restored jaw of Edestosaurus dispar (× ⅙).

Meuse, and hence the name. The body was covered with small overlapping bony plates. The paddles, of which there were four, had the regular finger bones, as shown in Fig. 854 C, and hence more resembled those of a whale than those of the Enaliosaurs. The position of the teeth in the jaws is shown in Fig. 854 D; and one of them, from *Mosasaurus princeps* Mh., half the size of some in this species, is represented in Fig. 854 A. Besides these teeth, there were two rows of formidable teeth along the roof of the mouth, adapted (as in Snakes) for seizing their prey. Fig. 854 B represents the prolonged snout of one of the species. The most anomalous feature in their structure was

an articulation, for lateral motion, in either ramus of the lower jaw (at *a*), in place of the usual suture; and, besides, the extremities of the two rami were free, so that they served like a pair of arms in the process of swallowing any large animal whole.

Of Pterosaurs, remains of several species have been discovered in Kansas; two were twenty to twenty-five feet in expanse of wings, and another, eighteen feet. These American Pterosaurs are *toothless*, and are hence named by Marsh *Pteranodonts; anodont*, from the Greek, signifying *toothless*.

One of the Kansas Turtles, the *Atlantochelys gigas*, had, according to Cope, a breadth, between the tips of the extended flippers, of more than fifteen feet. The shell of a Turtle is made by the coalescence of the ribs in connection with the deposit of bone in the skin; and in the young state the ribs are free. Cope observes, that this ancient turtle was like the young of existing species in its ribs.

Birds. — While the American Pterosaurs were toothless, many of the Cretaceous Birds had numerous pointed teeth, as first observed by Marsh, who has hence called them *Odontornithes.* In one group, including the genus *Ichthyornis* of Marsh (see Plate V.), the vertebræ (Figs. 4, 5) are biconcave, and the teeth are set in sockets (Fig. 3). Fig. 1, of *I. victor*, is half the natural size; *I. dispar*, of Marsh, was as large as a pigeon. In the genus *Hesperornis* of Marsh (Plate IV.), the vertebræ had flat surfaces, and were like the modern, but the teeth (Fig. 4) were set in a groove (Fig. 2), as in most Reptiles; the skeleton is between that of the Ostrich and Loon, and *H. regalis*, of Kansas, was a gigantic Diver, five to six feet in height. There were also toothless birds related to the Cormorants and Waders.

Mammals. — Species must have been numerous, as they existed in the preceding period, but no relic of them has yet been found.

Characteristic Species.

1. Protozoans. — *Rhizopods.* — *Textularia Missouriensis*, *T. globulosa*, Ehr., *Phanerostomum senarium*, *Rotalia lenticulina*, *R. senaria* Ehr., *Grammostomum phyllodes*, from the Cretaceous of the Upper Missouri, identified by Ehrenberg; *Cristellaria rotulata* D'Orb., *Dentalina pulchra* Gabb, etc., from New Jersey; Fig. 829, *Orbitolina Texana* R., from Texas, a species having the form of a disk, slightly conical.

2. Radiates. — (*a.*) *Polyp-Corals.* — *Astrocœnia Sancti-Sabæ* R., Texas; *A. Guadaloupæ* R., Texas; *Montlivaltia Atlantica* Lonsd., New Jersey, etc.; *Trochosmilia granulifera* Gabb, Chico group, Chico Creek, California; *Trochosmilia conoidea* Gabb & Horn, New Jersey; *T.* (?) *Texana* Con., Texas; *Platytrochus speciosus* G. & H., Tennessee; *Flabellum striatum* G. & H., Alabama; *Micrabacia Americana* M., Nebraska.

(*b.*) *Echinoderms.* — *Holaster simplex* Shum.; *H.* (*Ananchytes*) *cinctus* Ag.; *Toxaster elegans* Gabb.; also species of *Diadema*, *Hemiaster*, *Holectypus*, *Cyphosoma*, etc.

3. Mollusks. — (*a.*) *Bryozoans.* — Numerous species have been described and figured by Gabb & Horn, of the genera *Membranipora*, *Flustrella*, *Escharipora*, *Biflustra*, etc.

(*b.*) *Brachiopods.* — Fig. 830, *Terebratulina plicata;* Fig. 831, *Terebratula Harlani* Mort., from New Jersey; *Lingula nitida* M. & H., Nebraska; *Rhynchonella Whitneyi* Gabb, Shasta group, California.

(*c.*) *Lamellibranchs.* — Fig. 833, *Ostrea larva* Lam., found also in Europe; *O. congesta* Con., from Arkansas and Nebraska; *Ostrea malleiformis* Gabb, Chico group, California; Fig. 832, *Exogyra arietina* R., from Texas; Fig. 834, *E. costata* Say, from the Cretaceous of the Atlantic and Gulf borders; *E. parasitica*, Gabb, Chico group, Texas Flat, California; Fig. 835, *Gryphæa vesicularis* Lam., at nearly all North American localities, including the Californian, and also a European species; Fig. 836, *G. Pitcheri* Mort., from Cretaceous region west of the Mississippi River; Fig. 837, *Inoceramus problematicus* Schloth., from west of the Mississippi, and also European. *Trigonia Tryoniana* Gabb, Chico group, California. Among Rudistes, *Radiolites Austinensis* R., a species five to six inches in diameter, from Alabama, Mississippi, and Texas; *Radiolites lamellosus* Tuomey, from Alabama; *Hippurites Texanus* R., a species eight inches long and four in diameter, from Texas; *Caprotina Texana* R., from Texas. *Haploscapha grandis* Con. is supposed to be related to the *Rudistes;* one Kansas specimen had a diameter of twenty-six inches; it is from the Niobrara group.

(*d.*) *Gasteropods.* — Fig. 838, *Pyrifusus Newberryi* M. & H., from Nebraska; Fig. 839, *Fasciolaria buccinoides* M. & H., from Nebraska; Fig. 840, *Anchura* (*Drepanocheilus*) *Americana* M. (= *Rostellaria Americana* Evans & Shumard), from Nebraska; Fig. 841, *Margarita Nebrascensis* M. & H., from Nebraska; Fig. 842, *Nerinæa Texana* R., from Texas; *N. acus* R., from Texas; Figs. 843 *a*, 843 *b*, *Bulla speciosa* M. & H., from Nebraska; *Margaritella angulata* Gabb, Chico group, California.

(*e.*) *Cephalopods.* — *Nautilus Texanus* Shum., Texas and California; Fig. 845, *Ammonites placenta* Dekay, from Atlantic Border, Gulf Border, and Upper Missouri, young specimen, natural size; Fig. 845 *a*, outline side view of the same, reduced; Fig. 845 *b*, one of the septa of the same, natural size; *Ammonites Brewerii* Gabb and *A. Haydenii* Gabb, and others, from Shasta group, Cottonwood Creek, California; Fig. 846, *Scaphites Conradi* Mort., from the same localities as preceding; Fig. 847, *S. larvæformis* M. & H., from Nebraska; *Hamites Vancouverensis* Gabb, Chico group, Vancouver Island; Fig. 848, *Baculites ovatus* Say, from New Jersey; Fig. 848 *a*, outline of section, showing oval form; Fig. 849, outline of section of *B. compressus* Say, Upper Missouri; *Baculites Chicoensis* Trask, California; *B. inornatus* M., Sucia Island, Gulf of Georgia; Fig. 850, *Nautilus Dekayi* Mort., from the Atlantic and Gulf borders, and west of the Mississippi from Texas to Upper Missouri, and also reported from Europe, Chili, and Pondicherry in the East Indies. Fig. 844, *Belemnitella mucronata* Schloth., same U. S. distribution as preceding, excepting the Upper Missouri region; *Belemnites impressus* Gabb, Shasta group, California; *Ancyloceras Remondii* Gabb, Shasta group, California; *Turrilites Oregonensis* Gabb, Chico group, Jacksonville, Oregon.

4. Vertebrates. — (*a.*) *Fishes.* — Fig. 852, *Otodus appendiculatus* Ag., from New Jersey. Figs. 853, 853 *a*, different views of a tooth of *Ptychodus Mortoni* (Cestraciont), a species found in New Jersey. *Pt. occidentalis* L., from Kansas. *Dipristis Meirsii* Mh., *Enchodus semistriatus* Mh.: also species of *Lamna*, *Oxyrhina*, etc.; *Beryx insculptus* Cope, *Edaphodon mirificus* L., all from New Jersey. The Cretaceous of Kansas has afforded Cope species of *Portheus* (one, *Portheus molossus* Cope, with a head as long as in a full-grown grizzly bear, and some of the slender sharp teeth projecting three inches), *Ichthyodectes*, *Saurocephalus*, *Cimolichthys*, *Enchodus*, etc.

(*b.*) *Reptiles.* — Among Dinosaurs, *Hadrosaurus Foulkii* L., from New Jersey, twenty-eight feet long; *H. minor* Mh., about half this in length, ibid.; *H. agilis* Mh., from Kansas. Among Crocodilians, *Hyposaurus Rogersi* Owen, a Teleosaurian, it having biconcave vertebræ; *H. ferox* Mh., with fluted teeth, from New Jersey; *Thoracosaurus Neocæsariensis* Cope, New Jersey, form and size near the same in the Gavial of the Ganges; *Holops obscurus* L., New Jersey; *H. brevispinis* Cope, New Jersey; *Bottosaurus Harlani* Ag., from New Jersey, related to the American Alligator. Among Enaliosaurs, *Discosaurus carinatus* L., near Fort Wallace, 300 miles west of Leavenworth; *Polycotylus latipinnis* Cope, Plesiosaur-like, eighteen feet long. Among Mosa-

saurs: Fig. 854 A, tooth of *Mosasaurus princeps* Mh., from New Jersey; *M. maximus* Cope, from New Jersey; *M. minor* Gibbes, from Alabama. Fig. 854 D, form of jaw of *Edestosaurus dispar* Mh., a species from Kansas, thirty feet long; Fig. 854 B, snout of *Tylosaurus micromus* Mh., from Kansas; *T. proriger* Mh. (*Leiodon proriger* Cope), from Kansas; *T. dyspelor* Mh. (*Leiodon dyspelor* Cope), fifty to sixty feet long, from Kansas, etc.; Fig. 854 C, paddle of *Lestosaurus simus* Mh., from Kansas, a short-nosed kind; *Clidastes iguanavus* Cope, from New Jersey; *C. intermedius* L., from Alabama; *C. pumilus* Mh., from Kansas, twelve feet long; *Baptosaurus platyspondylus* Mh. and *B. fraternus* Mh., both from New Jersey. The Mosasaurs, according to Marsh, have very short necks, like the Ichthyosaurs. The vertebræ, in the genera *Clidastes* and *Edestosaurus*, are united by a zygosphene articulation, as in snakes and the Iguanas.

Among *Pterosaurs*, *Pteranodon ingens* Mh., *Pt. occidentale* Mh., *Pt. velox* Mh., all from Kansas, severally about twenty-five, twenty, and fifteen feet in expanse of wings.

The birds comprise Waders, of the genera *Termatornis* and *Palæotringa*, from New Jersey; Natatores, of the genus *Laornis*, from New Jersey and Kansas; and birds with teeth, or Odontornithes, all from Kansas.

Of the last, the *Hesperornis* group has been called by Marsh, in allusion to the teeth in sockets, *Odontolcæ*. The relations to the Ostrich are shown in the absence of a crest from the sternum, and in other characters (Marsh, Amer. Jour. Sci., xiv. 85, 1877). *H. gracilis* of Marsh is a second species. *Lestornis crassipes* Marsh, of the same family, was somewhat larger than *H. regalis*. *Baptornis advenus* Marsh, is supposed to be near Hesperornis; it was as large as the Loon. *Graculavus anceps* and *G. agilis* are two species from Kansas related to *Ichthyornis*.

The existence in Mosasaurs of the articulation in the lower jaw was first made known by Cope; and that of hind paddles and scales, as well as the character of the paddles, by Marsh. (Am. Jour. Sci., iii. 448, 1872.)

III. Fossils characteristic of the Subdivisions of the Cretaceous.

A. Earlier Cretaceous. — No. 1 (Dakota group). Upper Missouri: *Pharella* (?) *Dakotensis* M. & H., *Axinæa Siouxensis* Gabb., *Cardium*, *Corbicula*, *Yoldia*, *Tellina*, *Leptosolen Conradi* M., *Cyrena* (*Cyprina*) *arenaria* M.. *Unio Nebrascensis* M., *Leaves of Angiosperms*. Alabama: *Ceratites* (?) *Americanus* Harper, *Leaves of Angiosperms*. New Jersey: *Leaves of Angiosperms*.

No. 2 (Benton group). Upper Missouri: *Inoceramus problematicus*, *I. umbonatus* *Ostrea congesta*, *Pholadomya* (*Anatimya*) *papyracea* Con.; *Ammonites percarinatus* H. & M., *A. vespertinus* Mort. (= *A. Texanus* R.), *Scaphites larvæformis* M. & H. Texas: *Ammonites percarinatus*, *Inoceramus capulus* Shum. New Jersey: *none*.

No. 3 (Niobrara group). Upper Missouri: *Ostrea congesta*, *Inoceramus problematicus*, *I. aviculoides* M. & H., *I. pseudo-mytiloides* Schiel. Arkansas: *Toxaster elegans*, *Holaster simplex*, *Cardium multistriatum* Shum., *Inoceramus problematicus*, *I. confertim-annulatus* R., *Gryphæa Pitcheri*. Texas: *Holaster simplex*, *Epiaster elegans*, *Cidaris hemigranosa*, *Gryphæa Pitcheri*, *Ostrea subovata* Shum. (*O. Marshii* Marcou), *Inoceramus problematicus*, *Turrilites Brazoensis* R., *Ammonites Texanus*, *Hamites Fremonti* Marcou. New Jersey: *none*.

B. Later Cretaceous. — No. 4 (Pierre group). Upper Missouri: *Nautilus Dekayi*, *Ammonites placenta*, *A. complexus* H. & M., *Baculites ovatus*, *B. compressus*, *Helicoceras Mortoni* M. & H., *Inoceramus sublevis* H. & M., *Mosasaurus Missouriensis* L. Alabama: in bed *a*, *Teredo tibialis* (?) Mort.; in bed *b*, *Exogyra costata*, *Gryphæa vesicularis*, *Inoceramus biformis*, *Pecten 5-costatus* Mort., *Nautilus Dekayi* Mort., *Ammonites placenta*, *A. Delawarensis* Mort., *Baculites ovatus*; in bed *c*, *Ostrea larva*, *Gryphæa lateralis* (*G. vomer* Mort.), *Neithea Mortoni* Gabb. New Jersey: Bed *a*, *Ammonites placenta*, *Baculites ovatus*; bed *b*, *Amm. Delawarensis*, *A. complexus*, *Bacu-*

lites ovatus, *Nautilus Dekayi*, *Belemnitella mucronata*; bed *c*, *Terebratulina plicata*, *Pholadomya occidentalis* Mort., *Ostrea larva*, *Gryphæa vesicularis*, *Exogyra costata*, bones of *Mosasaurus*.

No. 5 (Fox Hills group). Upper Missouri: *Nautilus Dekayi*, *Amm. placenta*, *A. lobatus* Tuomey, *Scaphites Conradi*, *Baculites ovatus*, *Mosasaurus Missouriensis*. Alabama: *Exogyra costata*, *Gryphæa vesicularis*, *Nautilus Dekayi*, *Baculites ovatus*, *Scaphites Conradi*. New Jersey: *Montlivaltia Atlantica*, *Nucleolites crucifer*, *Ananchytes cinctus*, *A. fimbriatus* Mort., *Terebratula Harlani*, *Gryphæa lateralis*, *G. vesicularis*, *Neithea Mortoni*.

The New Jersey region abounds in *Oysters* and *Exogyræ*, has some *Ammonites*, *Baculites*, and *Echinoderms*, but no *Hippurites* or *Caprinæ*.

The Upper Missouri has very few *Oysters*, no *Exogyræ*, many and large *Ammonites* and *Baculites*, but one rare *Echinoderm* (*Hemiaster Humphreysianus* M. & H.), no Brachiopods, except two *Lingulæ*, and no *Hippurites* or *Caprinæ*.

The Alabama beds resemble the New Jersey, and the Arkansas the corresponding or middle beds of Nebraska, and upper of New Jersey; but both contain *Hippurites* and *Echinoderms*.

The Texas region has but few species in common with the others, — *Ammonites vespertinus*, *Inoceramus latus* (?), and *I. Barabini*, the latter being still questioned; and it is characterized by *Hippurites*, *Caprinæ*, *Nerinææ*, etc., like the Upper Chalk of southern Europe.

The species common to Nebraska and New Jersey, according to Meek & Hayden, are *Nautilus Dekayi*, *Scaphites Conradi*, *Ammonites placenta*, *A. complexus*, *A. lobatus*, *Baculites ovatus*, *Amauropsis* (?) *paludinæformis* M. & H.

2. Foreign.

I. Rocks: kinds and distribution.

The Cretaceous formation covers a large part of southeastern England, eastward of the limit of the Jurassic, from Dorset on the British Channel to Norfolk on the German Ocean; and also a narrow coast-region, about, and south of, Flamborough Head, as shown on the map, p. 344. Like the Jurassic, it reappears again in northern France, across the British Channel. It also occurs in other parts of France, in Sweden, and in southern and central Europe, covering much of the territory between Ireland and the Crimea, 1,140 miles in breadth, and, between the south of Sweden and south of Bordeaux, 840 miles. (Lyell.)

The rocks are (1) Sandstone, generally soft, and of various colors; (2) marlytes or clayey beds; (3) the variety of limestone called *Chalk*, the common writing material, in beds of great thickness; (4) other limestones, either loose or compact. Among the sandy portions, the *Green-sand* beds are a marked feature, especially of the lower part of the formation. This is so eminently the fact that the Lower Cretaceous in England is called the *Green-sand*, although only a part of the layers are green, and in some regions none at all.

The Chalk often contains *flint*, in nodules, which are distributed in layers through it, like the hornstone in earlier limestones. Though generally more or less rounded, they often assume fantastic shapes,

and are of concretionary origin. The exterior is frequently white, and penetrated by chalk, proving that they are not introduced bowlders or stones, but have originated where they lie. Moreover, many chalk fossils are turned into flint; and the flint nodules have often fossils as nuclei.

The Cretaceous beds of Europe have been divided into: —

I. The *Lower Cretaceous*, including in England the *Lower Green-sand*, 800 to 900 feet thick, and in other regions beds of clay, and limestone sometimes chalky.

II. The *Middle Cretaceous*, including in England (*a*) the clayey beds or marlytes, called *Gault*, 150 feet thick, and (*b*) the *Upper Green-sand*, 100 feet.

III. The *Upper Cretaceous*, including in England the beds of Chalk, in all about 1,200 feet: it consists of (*a*) the *Lower* or *Gray Chalk*, or *Chalk Marl*, without flint; (*b*) the *White Chalk*, containing flint; (*c*) the *Maestricht beds*, rough friable limestone, at Maestricht in Denmark, 100 feet thick.

The subdivisions of the Cretaceous are variously named, in different parts of Europe.

Lower Cretaceous. — Superior Neocomian of D'Orbigny (the Wealden being the Inferior); the Hils-conglomerat of Germany.

Middle Cretaceous. — 1. *Gault*, lower part Aptian, of D'Orbigny; the upper, Albian of D'Orbigny; 2. *Upper Green-sand*, Cenomanian of D'Orbigny; Lower Quadersandstein (or Unterquader) of the Germans; Lower Plänerkalk of Saxony.

Upper Cretaceous. — 1. *Gray Chalk*, or *Chalk without flints*, Turonian of D'Orbigny; Hippurite Limestone of the Pyrenees; Middle and Upper Plänerkalk of Saxony; Mittelquader of Germany. 2. *White Chalk* or *Chalk with flints*, Senonian of D'Orbigny; Upper Quadersandstein (Oberquader) of the Germans; La Scaglia of the Italians. 3. *Maestricht beds*, of Limburg; Danian of D'Orbigny; Faxoe Kalke of Denmark; Calcaire pisolitique near Paris.

In mineral character, the beds of each division vary much over Europe, the Chalk of England being synchronous with marlytes and solid limestones in Europe.

The Cretaceous of Great Britain is not found on any part of the Atlantic coast, excepting a small area in the vicinity of the Giants' Causeway. The beds of northern France spread eastward over Belgium and Westphalia, but not to the Atlantic on the west: farther south, they occur at the deep indentation of the Bay of Biscay. They cover part of the Pyrenees, and reach into Spain, in what has been called the *Pyrenean basin*, which in the Cretaceous period was a bay on the Atlantic. There is another sea-border deposit at Lisbon, in Spain. In southern France, over what is called the *Mediterranean basin*, the beds extend from the Gulf of Lyons along the Mediterranean coast, northeast to Switzerland, though with interruptions. The formation is found in the Juras and Alps, in Italy, Savoy, Saxony, Westphalia, Moravia, Bohemia, northern Germany, Poland, middle and southern Russia, Greece, and other places in Europe.

In Asia, it has been observed about Mount Lebanon and the Dead Sea, the Caucasus, in Circassia and Georgia, and elsewhere; in northern and southern Africa; in South America, along the Andes, and on the Pacific coast, occurring in Venezuela, in Peru, at Concepcion in Chili, in the Chilian Andes at the passes of the Portillo and Rio Volcan, at an elevation of 9,000 to 14,000 feet, in the Straits of Magellan at Fort Famine in Fuegia.

The Cretaceous formation occurs also in Queensland (northeast Australia), and in Victoria, west of Flinders river. It also exists in North Greenland, where some of the fossil leaves are identical in species with European.

II. Life.

The Life of the Cretaceous period in Europe resembled that of America, but was far more abundant.

1. *Plants.*

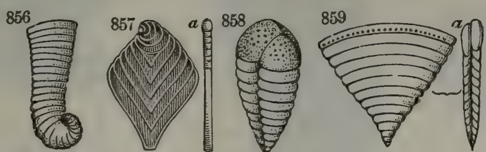
Angiosperms and Palms were growing in Europe; and, among the former, there were the Magnolia, Myrtle, Willow, Walnut, Maple, Fig, and Holly, besides a Redwood (*Sequoia*) and a *Palmacites*. The relics of Ferns, Conifers, and Cycads still preponderate; for the Cretaceous was properly the closing part of the era of Cycads. Vegetable remains of all kinds are rare, as the deposits are mostly marine.

The microscopic Protophytes, called Diatoms and Desmids, are found in some of the beds, especially in the flint of the Chalk. The former have siliceous cases, as explained and illustrated on p. 135, and they may have contributed, as has been suggested, to the material of the flint nodules. The Desmids are not siliceous, but are still very common in the flint,—far more so than Diatoms (which are rare): the kinds which have been called Xanthidia are especially abundant; their forms are very similar to those from the Devonian hornstone, figured on p. 257. The microscopic Coccoliths, alluded to on p. 135, have been detected in Chalk.

2. *Animals.*

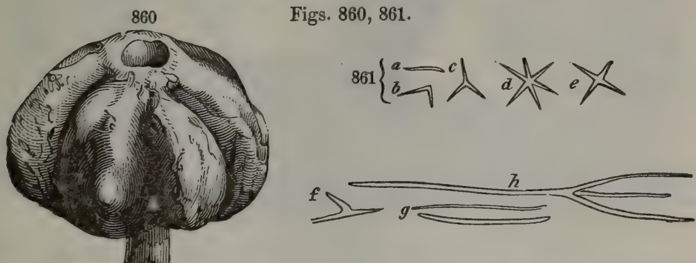
Foraminifers, or the shells of Rhizopods, are the principal material of the Chalk. According to Ehrenberg, a cubic inch of it often con-

Figs. 856–859.



Rhizopods.—Fig. 856, Lituola nautiloidea; 857, *a*, Flabellina rugosa; 858, Chrysalidina gradata; 859, *a*, Cuneolina pavonia.

Figs. 860, 861.



Sponge, Fig. 860, Siphonia lobata. Fig. 861 *a–h*, Sponge Spicules.

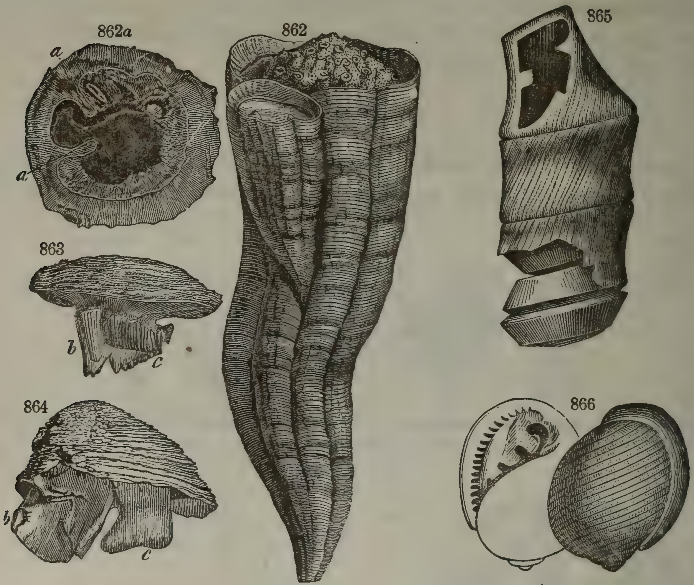
tains more than a million of microscopic organisms, among which far the most abundant are these Rhizopods. Some of the species are represented in Figs. 856–859.

Sponges, also, were of great importance in the history of the Cretaceous rocks. They occur cup or saucer-shaped, tubular, branched, and of other forms. One is figured in Fig. 860. Their siliceous spicula (Fig. 861 *a–g*) are common in the flint, and have contributed, as well as Diatoms, toward the silica of which it was made. The recent discovery over the ocean's bottom of sponges whose fibres are wholly siliceous, shows that these species may have contributed much to flint-making. The *Ventriculites* of the chalk are supposed to have been siliceous Sponges.

Among Radiates, the Corals and Echinoids were mostly of modern types.

The same genera of Mollusks abounded that are enumerated on p. 460. The genera of Gasteropods were to a greater extent modern genera than in the preceding period; and the proportion of siphonated

Figs. 862–866.



CONCHIFERS, *Rudistes* Family.—Fig. 862. Hippurites Toucasianus; 862 *a*, H. dilatatus; 863, Radiolites Bournoni; 864, Spherulites Hœninghausi. GASTEROPODS.—865, Nerinæa bisulcata; 866 Avellana Cassis.

species (those having a beak) was nearly as great as in existing seas. The *Rudistes* (Figs. 862–866) were very common in southern Europe and Asia Minor; and about eighty species have been described. Only a single species — *Radiolites Mortoni* Woodw. — has been found in

England. The Ammonites and the uncoiled forms of the same family mentioned on p. 462, several of which are here figured (Figs. 867–871) were particularly abundant. One English Ammonite (the *A. Lewesiensis* Mant.), from the Lower Chalk, has a diameter of a yard.

Figs. 867–871.

CEPHALOPODS, *Ammonite* Family. — Fig. 867, Crioceras Duvalii; 868, Ancyloceras Matheronianum; 869, Hamites attenuatus; 870, Toxoceras bituberculatum; 871, Turrilites catenatus.

In the sub-kingdom of Vertebrates, there were Fishes of the modern order of *Teliosts*, or *Osseous* fishes, and Sharks of the modern

Fig. 872.

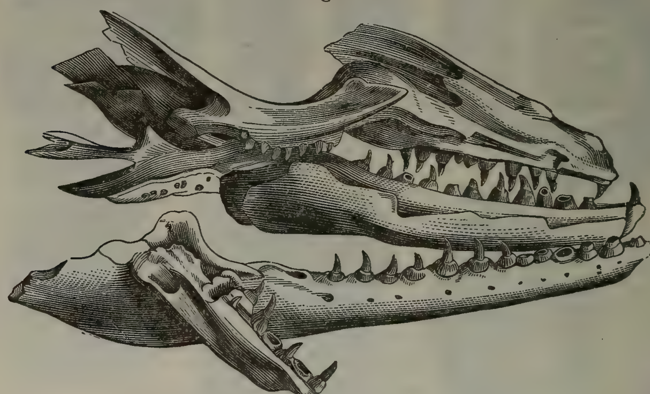
TELIOST. — Osmeroides Lewesiensis (×¼).

tribe of *Squalodonts*, as stated with regard to America. One of these Osseous fishes is represented in Fig. 872. They included representa-

tives of the Salmon and Perch families. The teeth of Cestraciont Sharks are common.

The class of Reptiles, in the earlier part of the Cretaceous period, included the *Iguanodon* and *Teleosaur*. Both then and later, there were *Plesiosaurs* and *Icthyosaurs;* other swimming Saurians, called *Polyptychodon* by Owen, nearly fifty feet long; over a dozen species of *Pterodactyls*, one of which was twenty-five feet in the spread of its wings; also, in the later part, a *Mosasaur*, probably forty-five feet long (Fig. 873); besides other large species.

Fig. 873.



Mosasaurus Hofmanni ($\times\frac{1}{18}$).

Of the class of Birds, two species have been found near Cambridge, England, about as large as Pigeons, and probably related to the Gulls.

Characteristic Species.

1. Protozoans. — (*a.*) *Sponges.* — Fig. 860, *Siphonia lobata*, from the Chalk. Over one hundred species related to the Sponges occur in the Cretaceous strata of England. *Scyphia*, *Spongia*, and *Ventriculites* are the more common genera.

(*b.*) *Rhizopods.* — Fig. 856, *Lituola nautiloidea* Lam.; Fig. 857, *Flabellina rugosa* D'Orb.; Fig. 857 *a*, profile of same; Fig. 858, *Chrysalidina gradata* D'Orb.; Fig. 859, *Cuneolina pavonia* D'Orb.; Fig. 859 *a*, profile of same; all much magnified. Other genera are *Rotalia*, *Textularia*, *Nodosaria*, etc. The Chalk formation of England has afforded over one hundred and twenty species, and between twenty and thirty genera, and among them two species of the genus *Orbitolina*, an American species of which is represented in Fig 829.

2. Radiates. — (*a.*) *Polyp-Corals.* — Species of *Cyathina*, *Trochocyathus*, *Trochosmilia*, *Parasmilia*, *Micrabacia*, etc.

(*b.*) *Echinoderms.* — Species of the genera *Cidaris*, *Diadema*, *Cyphosoma*, *Hemiaster*, *Cardiaster*, *Galerites*, *Holaster*, *Micraster*, etc.; also Crinoids, of the genus *Marsupites*, etc.

3. Mollusks. — (*a.*) *Bryozoans.* — Genera *Eschara*, *Escharina*, *Vincularia*, *Flustra*, *Cricopora*, etc.

(*b.*) *Brachiopods.* — Numerous species of *Terebratula*, *Terebratella*, *Terebratulina*, *Rhynchonella*, *Crania*, *Thecidea*, etc.

(*c.*) *Lamellibranchs.* — Species of *Gryphæa*, *Exogyra*, *Inoceramus*, *Gervillia*, *Trigonia*, — all extinct; also of *Cardium*, *Astarte*, *Cardita*, *Corbula*, *Isocardia*, *Lima*, *Crassatella*, *Cyprina*, *Cytherea*, *Venus* (?), *Lucina*, *Panopæa*, *Avicula*, *Pecten* (?), *Neithea*, *Pholas*, *Spondylus*, *Tellina*, *Plicatula*, and many other genera of existing seas, which give a modern aspect to a conchological cabinet of the Cretaceous period. Among the species of the extinct tribe of *Rudistes*, Fig. 862, *Hippurites Toucasianus* D'Orb., from the Upper Cretaceous, one of the most common species of southern Europe; Fig. 862 *a*, *H. dilatatus* Defr., vertical view, showing the interior of the lower conical valve, from the Lower Cretaceous; Fig. 863, *Radiolites Bournoni* D'Orb., upper valve in profile, from the Upper Chalk; Fig. 864, *Sphærulites Hœninghausi* Desm., upper valve in profile, from the Upper Chalk; *b*, *c*, in 863, 864, attachments of muscles.

(*d.*) *Gasteropods.* — The extinct genera *Nerinæa*, *Actæonina*, *Actæonella*, *Avellana*, etc. The modern genera VOLUTA, *Oliva*, FASCIOLARIA, OVULA, CYPRÆA, *Trochus*, *Nerita*, *Natica*, *Mitra*, *Conus*, *Cerithium*, *Bulla*, etc., showing a striking approximation to the present age, in the closing period of the Mesozoic. (The genera in small capitals are some of those which are supposed to have made their first appearance in the Cretaceous period.) Fig. 865, *Nerinæa bisulcata* D'Archiac, from the White Chalk. Fig. 866, *Avellana Cassis* D'Orb., from the Upper Green-sand; *a*, outline sketch, showing the toothed aperture.

(*e.*) *Cephalopods.* — Ammonites: Fig. 867, *Crioceras Duvalii* Léveillé, from the Lower Cretaceous; Fig. 868, *Ancyloceras Matheronianum* D'Orb., Lower Cretaceous; Fig. 869, *Hamites attenuatus* Sow., Middle Cretaceous; Fig. 870, *Toxoceras bituberculatum* D'Orb.; Fig. 871, *Turrilites catenatus* D'Orb., Gray Chalk. Also *Baculites* (as *B. anceps* Lam., etc.). — Also *Belemnitella mucronata* D'Orb., a common species of the Upper Cretaceous; also species of *Belemnites* and *Conoteuthis*.

4. Articulates. — Worms of several genera. Crustaceans, of the Brachyural genera, *Grapsus*, *Podophthalmus*, *Podopilumnus*, *Arcania*, *Notopocorystes*, etc.; and the Macrural, *Scyllarus*, *Callianassa*, *Palæastacus*, etc. Of the tribe of Cirripeds, *Tubicinella*, *Pollicipes*. Also Ostracoids.

5. Vertebrates. — (*a.*) *Teliost Fishes.* — Fig. 872, *Osmeroides Lewesiensis* Ag., from the Chalk at Lewes, — a fish of the Salmon family (Cycloid) related to the Smelt (genus *Osmerus*), and about fourteen inches in length. Another species of the genus, from the same beds, *O. Mantelli* Ag., is eight or nine inches long. There were other Cycloids, of the genus *Clupea* (Herring), etc. Several species of *Beryx*, a genus related to the Perch (Ctenoid), occur in the Chalk; one, *B. Lewesiensis* Dixon, is a broad fish, six to twelve inches long; another, *B. superbus* Eg., sometimes thirteen inches long. *Ganoids* were numerous in species, of the genera *Belonostomus*, *Caturus*, *Lepidotus*, etc., besides others of the Pycnodont family, *Pycnodus*, *Gyrodus*, etc. Sharks of the Hybodont family were sparingly represented: Cestraciont remains were very common, especially of the genera *Ptychodus* and *Acrodus*. Teeth of Squalodonts are occasionally met with, of the genera *Carcharias*, *Lamna*, *Oxyrhina*, *Odontaspis*, etc.

(*b.*) *Reptiles.* — Fig. 873, *Mosasaurus Hofmanni* Mant., head from the Chalk at Maestricht, one eighteenth the natural size; a species which has been found also at Lewes in England. In the figure, the articulation in the lower jaw is concealed by the fragment of a jaw overlying it; and hence its existence was never found out from the study of the specimen.

Leiodon, *Raphiosaurus*, and *Coniosaurus* are other genera of the Upper Cretaceous. The genera *Ichthyosaurus*, *Plesiosaurus*, and *Pterodactylus* reach even into the Upper Cretaceous: *Iguanodon* and *Teleosaurus* occur in both Lower and Upper Green-sand in England.

The several divisions have the following characteristic fossils: —

I. LOWER CRETACEOUS. — 1. Lower Green-sand, or Neocomian. — *Holocystis elegans* E. & H., *Toxaster complanatus* Ag., *Rhynchonella Gibbsiana* Dav., *R. depressa* D'Orb., *Terebratula sella* Sow., *Ostrea Leymerii* Desh., *Exogyra sinuata* Sow., *E. Couloni* D'Orb., *Gervillia anceps* Desh., *Myacites mandibula* Sow., *Perna Mulleti* Desh., *Trigonia dædalea* Park., *T. caudata* Ag., *Pleurotomaria gigantea* Sow., *Pterocera Fittoni*

Forbes, *Ammonites Martini* D'Orb., *Ancyloceras gigas* D'Orb., *Belemnites dilatatus* Blainv., *Crioceras Duvalii*; *Iguanodon*, *Pterosaurs*, etc.

II. Middle Cretaceous. — 1. Gault (Albian). — *Cyathina Bowerbankii* E. & H., *Trochocyathus Fittoni*, *T. conulus* E. & H., *Trochosmilia sulcata* E. & H., *Hemiaster Bailyi* Forbes, *Pentacrinus Fittoni* Austin; *Inoceramus concentricus* Park., *I. sulcatus* Park., *Rostellaria carinata* Mant., *Ammonites dentatus* Sow., *A. splendens* Sow., *A. varicosus* Sow., *Belemnites minimus* Lister, *Hamites attenuatus* Sow., *H. rotundus* Sow., *Ancyloceras spiniger* D'Orb. In the lower part (Aptian or Speeton Clay), *Belemnites Brunswickensis*, *Ammonites nisus* D'Orb., *A venustus* Phill., *Plicatula placunea*, Lam.

2. Upper Green-sand (Cenomanian). — *Siphonia pyriformis* Goldf., *Verticillites anastomosans*, *Micrabacia coronula* E. & H., *Holaster subglobosus* Ag., *H. carinatus*, *Diadema Bennettiæ* Forbes, *Echinus granulosus* Münst., *Cidaris vesiculosa* Goldf.; *Rhynchonella latissima* Dav., *Terebratella pectita* D'Orb., *Terebratula biplicata* Defr., *Arca carinata* Sow., *Exogyra columba* Goldf., *E. lateralis* Dubois, *Gryphæa vesiculosa* Sow., *Ostrea frons* Park., *Pecten asper* Lam., *Pecten quinquecostatus*, *Inoceramus striatus* Mant., *Trigonia dædalea*, *Protocardium Hillanum*, *Caprina adversa*, *Ammonites auritus*, *A. rostratus* Sow., *A. Rhotomagensis* Brngt., *A. varians*, Sow.; *Iguanodon*, *Teleosaurus*, *Ichthyosauri*, *Pliosaurus*, *Pterodactyls*; birds mentioned above.

III. Upper Cretaceous. — 1. Lower part (Turonian). — *Stephanophyllia Bowerbankii* E. & H., *Galerites conicus* Desor, *Holaster subglobosus* Ag.; *Inoceramus mytiloides* Mant., *I. Brongniarti* Sow., *Exogyra columba* Goldf., *Ostrea frons*, *Lima Hoperi* Desh. *Plicatula inflata* Goldf., *Trigonia scabra* Lam., *Ammonites complanatus*, Brngt., *A. peramplus* Mant., *Baculites anceps*, *Belemnitella plena* Sharpe, *Hamites simplex* D'Orb., *Scaphites equalis* Sow., *S. Geinitzii* D'Orb., *Turrilites costatus* Lam.; *Dolichosaurus*, *Icthyosaurus*, *Plesiosaurus*, *Polyptychodon*, *Pterodactylus Cuvieri* Bowerbank.

2. Upper part of Upper Cretaceous (Senonian). — *Siphonia pyriformis*, *Choanites Königii*, Mant., *Ventriculites decurrens* Smith, *V. radiatus* Mant., *Cristellaria rotulata* D'Orb., *Rotalina ornata* Morris, *Ananchytes ovatus* Lam.; *Cardiaster granulosus* Forbes, *Galerites albogalerus* Lam., *Marsupites ornatus* Miller, *Micraster Cor-anguinum* Ag.; *Terebratula carnea* Sow., *Ostrea vesicularis* Lam., *Exogyra conica* Sow., *Inoceramus Brongniarti* Sow., *I. Cuvieri* Sow., *Hippurites organisans* Desmoulins, *Baculites anceps*, *Nautilus Danicus* Schlot., *Turrilites polyplocus* R., *Belemnitella mucronata*; *Beryx Lewesiensis* Mant., *Osmeroides Lewesiensis* Ag., *Mosasaur*, etc.

Species of Wide Geographical Distribution.

The following species are reported from different continents (Bronn): —

Ostrea larva, North America; Europe; India. *Gryphæa vesicularis*, North America; Europe; southwest Asia. *Exogyra levigata* Sow., Europe; Columbia, South America. *Exogyra Boussingaultii* D'Orb., Europe; Columbia, South America. *Inoceramus Crispii* Mant., North America; Europe. *Inoceramus latus* Mant., North America; Europe. *Inoceramus mytiloides* Mant., North America; Europe. *Neithea Mortoni*, North America; Europe; India; Peru, South America. *Pecten circularis* Goldf., North America; Europe; India; Peru, South America. *Trigonia limbata* D'Orb., North America; Europe; India. *Trigonia aliformis* Sow., North America; Europe; southwest Asia; Columbia, South America. *Trigonia longa* Ag., Europe; Columbia, South America. *Hippurites organisans*, Europe; southwest Asia; Peru and Chili, South America. *Nerinæa bisulcata* D'Arch., North America (Texas); Europe. *Baculites anceps*, North America; Europe; Chili, South America. *Ammonites vespertinus* Mort., North America; Europe.

The following *Ammonites*, according to D'Orbigny, are common to Europe and South America: *A. Bogotensis* Forbes, *A. Dumasianus* D'Orb., *A. Didayanus* D'Orb., *A. galeatus* Buch., *A. Vandeckii* D'Orb., *A. Tethys* D'Orb., *A. prælonga*, *A. simplus* D'Orb., besides others. The Echinoid *Toxaster complanatus* Ag. & D. is said to have the same range.

The following table of species in the Earlier and Later Cretaceous of America,

showing their relations to species of the corresponding divisions in Europe, is from a paper by Meek & Hayden: —

Earlier Cretaceous W. of Miss. R.	Lower or Gray Chalk in Europe.
Ammonites vespertinus Mort.	occurs in Austria.
A. percarinatus H. & M.	probably identical with *A. Woolgari* Mantell.
Scaphites Warreni M. & H.	scarcely distinct from *S. æqualis*, Sowerby.
S. larvæformis M. & H.	same type as *S. æqualis*.
Nautilus elegans, var.	scarcely distinct from *N. elegans* Sowerby.
Inoceramus latus (?)	appears to be the same as *I. latus* Mantell.
I. problematicus	cannot be distinguished from *I. problematicus* Schlot.; reported also from the Upper Greensand of Europe.

Species common to the Later Cretaceous of America and the Upper or White Chalk of Europe: *Saurocephalus lanciformis* Harlan, *Lamna acuminata* Ag., *Belemnitella mucronata*, *Neithea Mortoni*, *Ostrea larva*, *Gryphæa lateralis*, *Gryphæa vesicularis*, *Nucleolites crucifer* Mort. The *Gryphæa vesicularis* is supposed by some to occur also in the Upper Green sand and the Lower or Gray Chalk; but the form found in these lower portions is regarded by other authorities as a distinct species.

Genera of the Later Cretaceous of America not yet found below the White Chalk of Europe: *Mosasaurus*, *Saurocephalus*, *Callianassa*, *Pleurotoma*, *Fasciolaria*, *Cypræa*, *Pulvinites*, *Cassidulus*. There are also in the American Later Cretaceous the two genera *Pseudobuccinum* and *Xylophaga* (?), which have not yet been found as low as the Cretaceous in Europe.

3. General Observations.

1. Origin of the Chalk and Flint. — From the absence of vegetable remains and earthy ingredients, the abundance of sponges, and the relations of the fossils to species now found in the deep Atlantic, it is supposed that the Chalk was formed at a distance of some miles from shore, where the water was at least several hundred fathoms deep. The abundance of Rhizopod shells, as already stated, suggests that these were the main material; and the recent observation that the lead in deep-sea soundings over the north Atlantic has often brought up sand composed almost wholly of minute Rhizopods, as first announced by Bailey, sustains the conclusion. These shells are like grains of sand in size, and are, therefore, ready for consolidation into a compact rock, needing no previous trituration by way of preparation; and thus they are especially fitted for making deep-water limestones. In the Atlantic, the mud of the bottom, where not over 2,500 fathoms in depth, is often eighty-five per cent. the shells of *Globigerina*, the kind of Rhizopod represented in Fig. 171; the most common species is *G. bulloides*. The softness or imperfect aggregation of Chalk is probably due to this origin, and particularly to the fact that each grain is a *cellular* shell, or collection of air-cells, instead of solid. The coral reefs of the Pacific do not under ordinary circumstances give rise to chalk. The only chalk known in coral regions is on Oahu, at the foot of an extinct volcanic cone; and there it is probable that warm waters

had some connection with its origin. Chalk appears to have been forming over the bottom of the ocean, where the depth does not exceed 15,000 feet, ever since the Cretaceous era, and probably from a period long anterior to this.

The Flint, as stated on page 471, has been attributed to the siliceous Infusoria of the same waters and the spicula of Sponges. In the soundings of various seas, microscopic siliceous shells of Infusoria (Diatoms or Polycystines) are as abundant as the Rhizopods in the Atlantic, which favors strongly this opinion. There are microscopic floating sponges, that becloud the sea-waters at times, as well as the large siliceous and more common kinds, all of which may have contributed to the result. The minute portion of silica which the alkaline waters of the ocean can dissolve — especially when the silica is in what is called the soluble state (p. 53), as is usual in these microscopic organisms — gives an opportunity for that slow process of concretion which might result in the flints of the Chalk. And the tendency to aggregation around some foreign body as a nucleus, especially when such a body is undergoing chemical change or decomposition, explains the frequent occurrence of fossils within flints, and the silicification of shells.

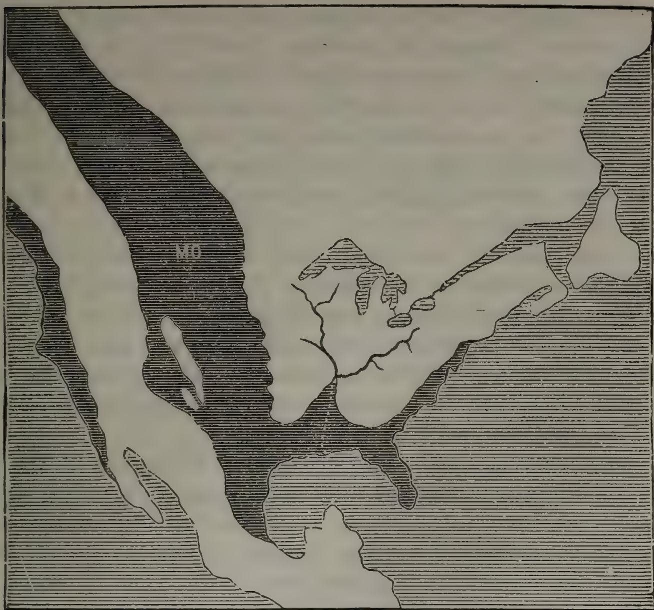
2. American Geography — The Cretaceous beds of New Jersey and of the rest of the border region of the continent, east and south, show, in their structure and position, and in the character of their fossils, that they were formed either along a sea-coast or in off-shore shallow waters. The limestones of Texas indicate a clearer sea; while the soft sandy and clayey formations to the north and northwest are evidence that the same sea spread in that direction, but was mostly of diminished depth. In the closing part of the Cretaceous, in the Rocky Mountain region, there was a change permanently from a condition of general submergence under salt water, to one of oscillations between emergence and submergence; and this condition continued on through a long era in the Eocene Tertiary, if the Coal series, excepting the lowest part, is of that age.

The outline of the Cretaceous formation over the continent points out approximately the outline of the sea in the Cretaceous period, and the general form of the dry land. This is presented to view in the accompanying map, in which the white part is the *dry land* of the continent, and the shaded the Cretaceous area, and therefore the *submerged* portion.

The line of the coast on the east extended from a point in New Jersey, to the southeast of New York City, across to the Delaware River, whose course it followed: this river, therefore, emptied into the Atlantic at Trenton; and the regions of the Delaware and Chesa-

peake bays were out at sea. From the Delaware, it continued southwestward, at a distance of sixty miles or more from the present coast-

Fig. 874.



North America in the Cretaceous period; MO, Upper Missouri region.

line between New Jersey and South Carolina. It next turned westward, being about one hundred miles from the Atlantic in Georgia, nearly two hundred miles from the Gulf in Alabama, and still more remote from the Western Gulf shore in Texas. The Appalachians stood at a less elevation than now, by sixty to six hundred feet.

The Gulf of Mexico, as the map illustrates, was prolonged northward, along the valley of the Mississippi, nearly to the mouth of the Ohio, making here a deep bay. Into it the two great streams entered, with only the mouth in common; and probably the Ohio was the larger, as its whole water-shed had nearly its present elevation and extent, while the Mississippi area was very limited. More to the westward, from the region of Texas, the Gulf expanded to a far greater breadth and length, stretching over much of the Rocky Mountain region, which was therefore so far submerged. It reached at least to the head-waters of the Yellowstone and Missouri (which rivers were, therefore, not in existence); and, judging from isolated observations in British America, the waters may have continued north-

westward to the Arctic seas, at the mouth of Mackenzie River, where beds of this period occur.

This Cretaceous Mediterranean Sea spread westward among several of the elevations of the Rocky Mountain summits; and, in New Mexico, it spread still farther westward, over the region of the Upper Colorado, to or beyond the meridian of 113° W. In California, it covered the region west of the base of the Sierra Nevada.

By comparing the above map with that of the Archæan (p. 149), it is seen that the continent had made great progress since the opening of the Silurian age. But, as all this Cretaceous area was under Cretaceous seas, much was still to be added to the permanent dry land before its completion.

The great Interior Continental basin, which had been a limestone-making region, for the most part, from the earliest period of the Silurian, was still, in its southern part, — that is, in Texas, — continuing the same work; for limestones eight hundred feet thick were there formed. To the north of Texas, where the waters were shallower, there appear to have been none of the Echinoderms, Corals, Orbitolinæ, etc., which were common in Texas.

3. Foreign Geography. — The distribution of the Cretaceous beds over other continents shows that the lands were to a great extent submerged. The sea covered a large part of the region of the Andes, as well as of the Rocky Mountains; and large portions of both chains were not yet raised into mountain-shape: the Alps, Pyrenees, and Himalayas were partly under water, or only in their incipient stages of elevation. Europe was mostly a great archipelago, with its largest area of dry land to the north; it resembled North America in the latter point, while widely differing in the former. The Urals and Norwegian mountains were the principal ranges of Europe, as the Appalachians and the Laurentian heights of Canada and beyond were in America. Western Britain was the high land of that region; and, under its lee and that of other lands southwestward across the Channel, the new formations of eastern England and northern France were in progress in deep waters bordering the German Ocean.

4. Climate. — The geographical distribution of species indicates a prevalence of warm seas in the northern hemisphere to the parallel of 60°, and in the southern to the Straits of Magellan. For the table on page 476 shows that several species are common to Britain, Europe, and either equatorial America, India, or the United States. The survey of the life of the period, therefore, so far as now known, affords no evidence of the existence of the present cool temperature in the waters of the temperate zone.

The corals of the Cretaceous beds in England may be those of cool

seas; but the coral reefs of central and southern Europe show that a large part of that continent was within the Cretaceous coral seas, or what is called the sub-torrid zone on the map of oceanic temperature. The warming influence of the Gulf Stream was less than in Jurassic times (p. 452). The present position of the winter line of 48° F., if drawn on the Physiographic chart, would probably run near that occupied by the line of 68° F. in the latter part of the Cretaceous period, except that the submergence of much of Europe would have given a very different sweep to the Gulf Stream.

The occurrence of a group of stones in the white chalk of southern England, the largest of syenyte and weighing forty pounds, appears to indicate, as Mr. Godwin Austin states, that there must have been floating ice in the sea at times.

There is a difference, in the later Cretaceous, between the species of northern and southern Europe, and also between those of the northern and southern United States, as explained on page 478; and this difference is probable due to diversity of temperature. There is a wide difference in North America, in the life of the two regions, Texas and the Upper Missouri; but, as Meek has remarked, this may be largely owing to the difference in the horizon of the beds, and also to that of the clearness or purity of the waters.

4. GENERAL OBSERVATIONS ON THE MESOZOIC.

I. Time-ratios.

An estimate of the comparative lengths of the Paleozoic ages is given on page 381. According to it, the lengths of the Silurian, Devonian and Carboniferous Ages are approximately as the ratio 4 : 1 : 1. The facts in European geology lead to probably the same result; the doubt arises from the uncertain thickness of the Primordial rocks.

The thicknesses of the Mesozoic formations lead, in a similar manner, to the *time-ratio* for the Paleozoic and Mesozoic nearly 4 : 1, and for the Triassic, Jurassic, and Cretaceous approximately 1 : $1\frac{1}{4}$: 1.

II. Geography.

Through the Mesozoic, North America was in general dry land; and on the east it stood a large part of the time above its present level. Rocks were formed on its southeastern and southern border, and over its great Western Interior or Rocky Mountain region. Europe, at the same time, was an archipelago, varying in the extent of its dry lands, with the successive periods and epochs. Rocks were

in progress along its more southern borders, and through its interior seas.

In Eastern America, and partly in Western, but few marked subdivisions of the formations can be made out, the Triassic and Jurassic making seemingly one continued series, and the Cretaceous another, with three or four subordinate divisions. In Europe, the number of epochal changes, or abrupt transitions in the rocks, is large, — much more so than in the Carboniferous age.

In Eastern America, there is but little limestone and little evidence of clear interior seas, except in the closing epoch of the Cretaceous in Texas, and some thin interpolations in the earlier formations ; and in Western, there is less of limestone in the interior region than of fragmental rocks. In Europe, the Lias and a large part of the Oölite and Chalk are limestone formations.

The facts indicate great simplicity in the oscillations of North America, and remarkable complexity and diversity of extent in those of Europe.

III. Life.

The following are some of the facts illustrating the general steps in the progress of life during the Mesozoic era : —

PLANTS. — Instead of forests of Conifers, Tree-ferns, and Lycopods (Lepidodendra, etc.), as in the Carboniferous, there were forests of Conifers, Tree-ferns, and Cycads ; and finally, in the Cretaceous period, these forests included also Angiosperms and Palms. The type of Cycads culminated in the Mesozoic, and afterward had relatively few representatives.

ANIMALS. — **1. Radiates.** — Corals of the Paleozoic type, having the parts multiples of four in number, the Cyathophylloids, were almost wholly wanting, while those of the modern Astræa type, having the rays a multiple of six, abounded.

Among Echinoderms, Crinoids, so abundant and important as rock-makers in the Paleozoic, were comparatively little numerous, while Echinoids and Starfishes were common.

Mollusks. — Brachiopods were vastly inferior in number of individuals to other higher species ; and the kinds which existed, as the *Terebratulæ*, etc., were inferior to those of earlier time, the type of Brachiopods having culminated in the Paleozoic era.

Gasteropods were, to a considerable extent, of modern genera ; but, unlike the moderns, the higher siphonated species (those having the aperture of the shell beaked), as well as the siphonated Lamellibranchs, were in the minority, these groups culminating in a subsequent era.

Among modern genera, the following occur in the Jurassic: *Rimula, Planorbis, Palu-*

dina, *Melania* (?), *Nerita*, *Pterocera*, *Tellina*, *Corbis*, *Anomia*, etc. In the Cretaceous: *Neithea*, *Crassatella*, *Axinæa* (*Pectunculus*), *Petricola*, *Venus* (?), *Oliva*, *Ovula*, *Cypræa*, *Voluta*, *Turris* (*Pleurotoma*), *Pseudobuccinum*, etc.

Cephalopods, the highest of Mollusks, culminated in the Mesozoic; and, in their culmination, the culmination of the grand type of Mollusks took place. This fact is strikingly exhibited in the history of the Ammonite and Belemnite groups. The genus *Goniatites*, a Paleozoic form of the Ammonite type, ended in the Triassic; but before this the earliest Ammonites had already appeared; and these continued afterward to increase in variety and numbers through the Mesozoic. Nearly 1,000 species of the Ammonite family have been found fossil in the Mesozoic rocks. Besides these, the *Belemnite* family — characterized by an internal shell — commenced in the epoch of the Lias; and over 120 of its species have been gathered from the Jurassic and Cretaceous strata. There were also many species of *Nautilus*. In existing seas, there are only *four* species of chambered external shells; and these belong to this latter genus. The Ammonite and Belemnite families died out, or nearly so, with the close of the Cretaceous period. It is to be noted that the above are the numbers of species of chambered shells *found fossil*: it may be but a small part of those which were actually in the waters of the era. The age was therefore remarkable for the great expansion of the type of Cephalopods.

The type began in the straight *Orthoceras*, with plain septa, and the half-coiled and equally simple *Lituites* of the Lower Silurian; it reached its maximum in the large and complex *Ammonite* of the Jurassic, and the associated *Belemnite* and Cuttle-fishes; it declined in the later Mesozoic, through the multiplication of the half-coiled forms of the Ammonite family (p. 462) and the straight *Baculite;* and, at the close of the period, there was a sudden disappearance of genera and species. Whether any of the modern Cuttle-fishes (Dibranchs) are equal, or superior, to the highest Cephalopods of the Jurassic, it is difficult to determine. The modern genus *Nautilus* — representing the chambered species (Tetrabranchs) — is certainly of far lower grade than the Jurassic Ammonite.

It is therefore one of the great facts connected with the Mesozoic era that, in its later half, the sub-kingdom of Mollusks passed its period of culmination. But, while this is true of the sub-kingdom as a whole, it is not true of each of its subdivisions; for the inferior tribes of Lamellibranchs and Gasteropods continue on the rising grade through the Mesozoic, and probably have their maximum display at the present time.

Articulates. — The class of Crustaceans rose to Macrurans (Shrimps and Lobsters) and true Crabs; and among the latter all the higher divisions were represented. The class of *Insects* was also un-

folded, even to its highest tribe, that of Hymenopters, species of this group, related to the bee, having occurred.

Vertebrates. — *Fishes.* — Ganoids and Selachians (or fishes of the Shark tribe) continued to be predominant kinds through the era; but the higher type of Teliosts (or common osseous fishes) appeared in the Jurassic, and included many species in the Cretaceous.

The Ganoids lost, in the Triassic, the Paleozoic feature of vertebrated tails; and this is a mark of progress; for it is an example of that abbreviation of the posterior extremity which generally marks elevation in grade as well as progress in embryonic development. In the Jurassic period, the number of species of Ganoids reached its maximum, and also the diversity of generic forms; and this therefore was their period of culmination. The Ganoids are at present nearly an extinct tribe.

The tribe of Sharks was numerously represented by large species of the Hybodont, Cestraciont, and other groups; and the family of Cestracionts, those having a pavement of bony pieces in the mouth, for mastication, appears to have passed its maximum in the Cretaceous: it is now nearly extinct. But the highest species of the Selachians existed later in the Tertiary.

Amphibians. — The scale-covered Amphibians, called Labyrinthodonts, which first appeared in the Carboniferous age, had gigantic species in the Triassic, and none afterward, so far as known. The type of Amphibians therefore culminated in the Triassic, the Labyrinthodonts being its highest species. We have now among Amphibians only the naked-skinned Frogs and Salamanders.

Reptiles. — All the grand divisions of this class were displayed, and the type culminated in this era.

The Enaliosaurs or Swimming Saurians of the Triassic — the *Nothosaur* type — had the open skull of a Batrachian; but, in the Jurassic, the group rose to the higher grade of the *Ichthyosaurs* and *Plesiosaurs;* and there were several genera and numerous species: with the Cretaceous, the species disappeared.

The Lacertians commenced in the Permian, in species with the ichthyic characteristic of biconcave vertebræ, and retained it through the Triassic and also in some Jurassic species. In the Triassic, Jurassic and Cretaceous, Crocodilians existed in many species of great size, and after the Triassic, some were without this low feature.

Snake-like Reptiles occurred, of enormous size, in the Mosasaur tribe, and with articulated jaws, precursors of our modern smaller snakes.

The Saurian type in the Jurassic rose to the grade of Dinosaurs, the highest in rank, and among the largest of Reptiles; and these all disappeared, by or soon after the close of the Cretaceous period.

There was also an expansion of the type to flying forms, the Pterosaurs, in the Jurassic; and this type continued into the Cretaceous, but then ended.

Thus, in all the grand divisions, there was a culmination and decline. The Reptilian type was unfolded in its complete diversity: the sea, air, and earth had each its species; and there were both grazing and carnivorous kinds, of large and small dimensions. Not only every species, but also every Mesozoic genus, with perhaps one or two exceptions, became extinct at or near the close of the era.

The reality of this Reptilian feature of the age will appear from a comparison of England as it was in Reptilian times with England as it is, or with all the world.

In a single era, that of the Wealden and Lower Cretaceous, — for the two were closely related in vertebrate species, — there were, in the British dominions of sea and land, four or five species of Dinosaurs, twenty to fifty feet long, ten or twelve Crocodilians, Lacertians, and Enaliosaurs, ten to fifty or sixty feet long, besides Pterodactyls and Turtles. As only part of the species in existence would have left their remains in the rocks, it would be evidently no exaggeration to increase the above numbers two or three fold. But, taking them as made out by actual discovery, the facts are sufficient to establish the contrast in view. For, since Man appeared, there is no reason to believe that there has been a single large Reptile in Britain. In India, or the Continent of Asia, there are but two species over fifteen feet long; in Africa, but one; in all America, but three; and not more than six in the whole world; and the length of the largest does not exceed twenty-five feet. The number of living species exceeding ten feet in length, is only sixteen or eighteen.

The Galapagos Islands are strikingly Reptilian at the present time. But they afford only four Lizards, as many Snakes, a Turtle, and a large Tortoise. The largest of the lizards, an *aquatic* species, of the genus *Amblyrhynchus* (having feet, however, instead of paddles), is but three to four feet long.

If so large a number of species as above mentioned existed in Britain and its vicinity during the age of Reptiles, what should be the estimate for the whole world at that time? The question is a good one for consideration, although no definite reply can be looked for.

As in the case of Mollusks, the culmination of the grand type does not imply a culmination of all its subdivisions. There is no evidence that the Mesozoic species of Turtles are superior in grade to those of the Cenozoic and the present age.

Birds. — Birds probably began in the Triassic, for, although the evidence from tracks in the Connecticut Valley Sandstone is doubtful,

it is not directly opposed to their existence; and, further, it is highly improbable that Mammals, the superior type of Vertebrates, should have existed before Birds. In the Jurassic, the occurrence of species is beyond question; and some of them, if not all, had that striking mark of inferiority, a long vertebrated tail, along with some other peculiarities that allied them to Reptiles, and especially to the three-toed Dinosaurs. In the Cretaceous era, the species were evidently numerous; and the most were of modern type. But among them were kinds with teeth and biconcave vertebræ, which were probably allied to the Jurassic birds.

Mammals. — The class of Mammals began in the Triassic, according to present knowledge, with species of the inferior tribe of Marsupials; and the same continued to be the prevailing kind through the rest of the Mesozoic. It is questioned whether there may not have been among them some species of Insectivores (the group to which the Mole and Shrew belong); but no higher species of ordinary Mammals than these have yet afforded even doubtful evidence of their existence. The Mammals were evidently far inferior in size and numbers, and in grade of life, to the Reptiles of the era.

IV. Disturbances during Mesozoic Time.

In American history, the displacements of the beds of the Triassic or Triassico-Jurassic areas on the Atlantic Border, and the multitudes of trap-dikes, which intersect these areas, indicate that their deposition was followed by an epoch of disturbance. The facts, and the conclusions from them, are stated on page 417. The time was either in some part of the Jurassic period, or at its close. The beds next in age along the Atlantic Border, the Cretaceous, did not participate in the upturning; and thus it is known that the ejections of trap took place anterior to the era they represent. The facts (1) that the trap-dikes are mostly confined to the sandstone areas; (2) that they consist of the same kind of dolerytic rock throughout, and (3) that the areas and the fractures are parallel to the preëxisting Appalachian chain, have been pointed to as evidence that all belong to one continental mountain-making movement.

On the Pacific border, at the close of the Jurassic, the lofty Sierra Nevada was made (p. 452); for the Cretaceous beds of California rest *unconformably* on the upturned Jurassic. Whether there were other cotemporaneous elevations west of the Rocky Mountain summit is not determined. In, and east of, the Wahsatch, the beds are all conformable from the base of the Paleozoic to the top of the Laramie group.

The Cretaceous strata of North America are throughout conformable. The positions of the successive beds indicate some oscillations

of level; and their thickness, — 10,000 feet in the Rocky Mountain region, and half that in California, — is proof of profound subsidences in progress; but all went on regularly and without intervening disturbances.

In Europe, during the progress of the Mesozoic, the rocks, Triassic, Jurassic, and Cretaceous, appear to have been laid down for the most part conformably, with few examples of non-concordance, yet with those variations in their distribution that arise from variations of the ocean's level, as a consequence of gentle heavings of the earth's crust. There were thus elevations and depressions producing the varying geography of the age, and successive destructions of species attending them, so that only a very small number of Liassic species has been found in the Oölyte, and less than a dozen of the Jurassic in the Cretaceous; while also many subordinate eras were separated by epochs of destruction.

A disturbance took place, between the Triassic and Jurassic periods, in the region of the Thuringian Forest and the frontiers of Bohemia and Bavaria, the Jurassic beds overlying unconformably the Triassic. This system of uplifts is named by De Beaumont the *System of the Thuringian Forest;* and the trend mentioned is N. 50° W. Again, between the Jurassic and Cretaceous, was formed De Beaumont's *System of the Côte D'Or*, having the trend N. 50° E.

The rocks of the Cretaceous and Jurassic are very nearly horizontal, in the great Anglo-Parisian region — the part of the German Ocean basin now exposed to view.

5. DISTURBANCES CLOSING MESOZOIC TIME.

The epoch of mountain-making which took place after the Mesozoic in North America, occurred at the close of the Laramie era; and at the close of the Cretaceous, if this coal-bearing series of the Rocky Mountains is true Cretaceous. This question of age is still undecided, the view of its Eocene age having as many and strong advocates as that of its Cretaceous age. If early Eocene, then the North American movements of the crust were nearly simultaneous with the European and Asiatic; for, there, some of the highest mountains date from the close of the Nummulitic section of the Eocene, or commenced there an addition of thousands of feet to their height.

But, if the mountain-making took place at this later date, there were other changes of vast influence; for at the close of the Cretaceous occurred one of the most complete exterminations of species of which there is record.

No species of the European Cretaceous is known to occur in the Tertiary formation, and none of Asia or of Eastern North America.

In the Rocky Mountain region, some Cretaceous species and genera continue on, if the coal series is Tertiary; and yet the number now known is less than half a dozen. The vast majority of the species, and nearly all the characteristic genera, disappear.

The facts do not authorize the inference that extermination was so complete as is implied in the above statement, although establishing that it was remarkable for its universality and thoroughness. It has been found that, in the bottom of the Atlantic, a living species of *Terebratula* (*T. caput-serpentis*) is probably identical with one of the Cretaceous species (*T. striata*), and several genera of corals, known hitherto only among Cretaceous fossils, have their species in the Atlantic depths, some of which differ but little from those of the Cretaceous. Such facts prove that the deep ocean was beyond the reach of the agencies that produced extermination over the Continental seas.

Cause of the Destruction of Life.—The general extermination of species at the close of the Cretaceous period was probably connected with changes of level, which took place at the time over the higher latitudes of America, Europe, and Asia, bringing on an era of unusual cold, and sending cold Arctic currents southward over the Continental seas. In North America, there are no marine Tertiary beds known north of southern New England, on the east, and none in the Arctic regions,—indicating, apparently, that the whole area was above the sea then, as now. This cause would have been sufficient to produce all the effects mentioned; and it appears to be the only cause that would be sufficiently complete and universal in its action. It is therefore most probable that the destruction was due (1) to the more or less complete emergence of the continents, especially their northern portions; and (2) to the change of climate and oceanic temperature thus occasioned,—both aerial and oceanic currents being rendered colder than in the Mesozoic era. This source of destruction would not have acted over the bottom of the Atlantic and other deep oceans; and hence species even of the Cretaceous era may survive there.

IV. CENOZOIC TIME.

It has been observed that, before the close of the Mesozoic, the mediæval features of the era were already passing away. The Cycads had begun to give place to the Sassafras, Tulip tree, Willow, Maple, Oak, and Palm; the ancient type of Ganoids, to Salmon, Perch, and Herring; and the Corals, Echini, and Mollusks, were in a great degree allied to those of existing seas, though of extinct species. But, notwithstanding these progressing changes, the Mesozoic aspect continued

on to the end, appearing prominently in the multitudes of Ammonites and Belemnites, in the predominance of Cestracionts and Ganoids among Fishes, and in the supremacy of the great class of Reptiles. Even the little Mammals, which appeared among the Reptiles, bore the mark of the age; for the larger part, at least, approximated to the oviparous Reptiles and Birds, in being themselves of a semi-oviparous type, the Marsupial.

But these Mammals were prophetic species: with the opening of a new era, the Reptiles dwindled in numbers, variety, and size; and Mammals in their turn became the dominant race. At the same time, types much like those of the age of Man were multiplied in all departments of nature. As the era advanced, species still living appeared,— a few among multitudes that became extinct, and afterward a larger proportion; and, before its close, nearly all kinds of life, excepting Mammals, were identical with those of the present era. As the Paleozoic or *ancient* life was followed by the Mesozoic or *Mediæval*, so now there was as marked a change to the Cenozoic or *recent* life and world.

Cenozoic time embraces two ages: —

I. The TERTIARY, or age of Mammals.

II. The QUATERNARY age, or age of Man.

I. THE TERTIARY, OR MAMMALIAN AGE.

Of the TERTIARY age, all the Mammalian species are extinct; and the proportion of living Invertebrates — Radiates, Mollusks, Articulates — varies from very few in the early part of the period to ninety-five per cent. in the latter part; while, of the Quaternary, a large part of the Mammalian species are extinct, but the Invertebrates are nearly all living, not over five per cent. being extinct.

The name Tertiary is a relic of early geological science. When introduced, it was preceded in the system of history by Primary and Secondary. The first of these terms was thrown out when the crystalline rocks so called were proved to belong to no particular age, — though not without an ineffectual attempt to substitute it for Paleozoic; and the second, after use for a while under a restricted signification, has given way to Mesozoic. Tertiary holds its place, simply because of the convenience of continuing an accepted name.

EPOCHS. — The earliest adopted subdivisions of the Tertiary were the Lower, Middle, and Upper. For these, Lyell substituted the following, based on the proportions of the fossils that belonged to species still living, namely, —

1. EOCENE, from ἠώς, *dawn*, and καινός, *recent* (the latter a root also in the word *Cenozoic*); the species nearly all extinct.

2. MIOCENE, from μείων, less, etc.; less than half the species living.

3. PLIOCENE, from πλείων, more, etc.; more than half the species living.

Some European geologists make a fourth division, called *Oligocene*, by separating an upper portion of the Eocene, and uniting with it the lower section of the Miocene; and a fifth, *Paleocene*, by so naming the lower division of the Eocene.

1. AMERICAN.

The periods recognized are, if the Laramie group is included: —

1. The LARAMIE or *Lignitic* period, represented partly by brackish-water beds, which in general are *unconformable* to the overlying Tertiary. After this —

A. *On the Eastern Border, where the beds are marine.*

2. The ALABAMA period, corresponding to the Eocene, and including (1) the *Claiborne* group, and (2) the *Vicksburg* group, which occur along the Gulf and Atlantic border.

3. The YORKTOWN period (named from Yorktown, Va.), which covers the Miocene, and possibly part of the Pliocene, and whose beds are found on the Atlantic border, from South Carolina to New England, and farther north off the coast, but not on the Gulf border.

4. The SUMTER epoch (named from a locality in South Carolina), corresponding to the Pliocene, or part of it.

B. *Over the Rocky Mountain slopes and west of the summit, where the beds are of fresh-water origin.*

2. The EOCENE is made to include the following groups, commencing below: (1) The *Wahsatch* (named from the Wahsatch Mountains); (2) the *Green River*, or the lower fish-bearing shales of the Green River Basin, perhaps cotemporaneous with the Wahsatch; (3) the *Bridger* (named from Fort Bridger), including the upper beds of the Green River Basin, etc., and containing bones of Mammals; (4) the *Uinta* (named from the Uinta Mountains).

3. The MIOCENE, includes the *White River* group, a part of the Upper Missouri region, where the beds have a wide extent.

4. The PLIOCENE includes the *Niobrara* group (named from a branch of the Missouri River), and other groups.

1. Rocks: kinds and distribution.

The deposits are either of marine or of fresh-water origin. The marine serve to mark out approximately the limits of the oceans over the continents, while the fresh-water are mostly of lacustrine origin.

The Tertiary areas on the map, p. 144, are lined obliquely from the left above to the right below; and the fresh and brackish-water Tertiary area, which occurs on the slopes of the Rocky Mountains, is distinguished from the *marine* by a more open lining.

The marine Tertiary beds occur on the *Atlantic Border*, in deep water along the banks off the coast of northern New England; on

Cape Cod, and the islands off southern New England; in New Jersey, and through Maryland, Virginia, and the Carolinas, over a narrow coast region, and, from South Carolina, westward along the *Gulf Border*, the inner limit of the region being about one hundred miles from the Gulf in Alabama, and one hundred and fifty to two hundred in Texas. Along the Mississippi River, the Gulf-border region extends northward to southern Illinois.

Marine Tertiary beds occur also on the Pacific coast, in California and Oregon, forming, with the Cretaceous, the Coast Range of hills. Some of the Tertiary ridges are 2,000 to 3,000 feet in height. They also cover the Cretaceous, over the Rocky Mountain slopes and summit, but alternate, in these parts, with extensive fresh-water beds.

Lignitic beds, referred to the Lower Eocene, are well displayed either side of the Mississippi, in Mississippi, Tennessee, and Arkansas.

The Laramie beds occur over the eastern slopes of the Rocky Mountains, on the Upper Missouri and elsewhere; over the Rocky Mountain region, in Wyoming, Utah, Colorado, etc., where the thickness is several thousand feet; in California, overlying the Cretaceous, and in other parts of the Pacific-border region. Lignite, or carbonized wood, and beds of mineral coal occur in the formation. Part of the beds outcrop near the Pacific Railroad; and the coal obtained, often called lignite, is used for the engines on the road, and for metallurgical and other purposes. The coal of Mount Diablo, California, and other beds of the Tejon series, appear to be of cotemporaneous formation.

The Eocene marine beds, of the Alabama period, are extensively displayed in the States of Mississippi, Alabama, and Georgia; they occur also at some points in South Carolina and Virginia, though generally concealed on the Atlantic border by the Miocene beds. They have been divided, commencing below, into the CLAIBORNE group, well displayed at Claiborne, Alabama, and the VICKSBURG group, so named from Vicksburg on the Mississippi. Lyell, whose observations in America as well as Europe first brought out the true character and relations of the Tertiary formations, makes the Claiborne beds to be probably the equivalent of the Middle Eocene of Great Britain, stating that several of the shells (among them, *Venericardia planicosta* Lam.) are identical with those of European species of that age.

The marine Miocene beds cover a large part of the Atlantic Border, and are well exhibited and full of fossils in Virginia and New Jersey.

Over the Rocky Mountain region and part of the Eastern slopes, the Tertiary beds later than those of the Laramie group are wholly of fresh-water origin; and they lie upon the upturned Laramie beds. As first shown by Hayden, the beds were formed in lakes that existed over the Rocky Mountain region, soon after it first emerged, and while it was yet low.

These fresh-water or lake deposits are, as stated, of all periods from the Eocene to the Pliocene. The *Eocene* existed over the Summit region, between the Wahsatch and the Front Range of the Rocky Mountains — one lake-basin north of the Uinta Range, in the Green River Basin, and another south, the latter reaching to New Mexico. The *Miocene* covered part of the eastern slopes along the White River, between the parallels of 40° and 44° — the *White River* Lake-basin of Hayden; also another in Central Oregon, along John Day River. A great *Pliocene* lake spread over the Miocene region of the Eastern slopes, and south nearly to the Mexican Gulf, and is called the *Niobrara* Lake-basin by Marsh; there was also another in Nevada; and a third in the North Park. The Eocene beds in the Mountains have a thickness of about 10,000 feet. In the Fort Bridger region, the strata, owing to erosion by rills and streams from the rains, stand in isolated earthworks or embankments, pyramids and spires, over the great plain, looking like a field of desolate ruins. Such areas in the Western Tertiary are called *Mauvaises Terres*, or *Bad Lands*, this name having been originally applied to one of the kind in the White River region.

Over the Coast region of California, the Tertiary formation is of marine origin, and has a thickness of at least 3,000 or 4,000 feet.

The Tertiary strata often vary greatly in character, from mile to mile. Instead of great strata of almost continental extent and uniformity, as in the Silurian, there is the diversity which exists among the modern formations of a sea-coast.

Off our present coasts, we find in one spot mud beds, with oysters or other Mollusks; in another region, great estuary flats; a little higher, on the same coast perhaps, accumulations of beach sands with worn shells, changing in character every few rods. The changes in the Tertiary strata are often equally abrupt. It should be noted also that coral limestones are now in progress off the Florida coast; and, on other shores, coarse shell-limestones. Still further, to comprehend the diversity in the deposits, it is necessary to remember that, by the throwing up or removal of embankments on coasts, or by change of level, salt-water marshes or estuaries become brackish-water, or wholly fresh-water, and the reverse, — each change being attended with a change in the living species of the waters.

The rocks are of the following kinds: *beds of sand* or *clay*, so soft as to be easily turned up by a shovel; *compact sandstones*, useful for a building-stone, though not very hard; *shell-beds*, of loose shells and earth, the shells sometimes unbroken, in other cases water-worn; *shell-rocks* and *calcareous sandstones*, consisting of pulverized shells and corals, firmly cemented and good for building-stone, as at St. Augustine; true *marls*, or clays containing carbonate of lime from pulverized shells, and hence effervescing with the strong acids; *compact solid*

limestones, sometimes oölitic in structure ; *green sand*, like that of the Cretaceous, and equally valued for fertilizing ; *buhrstone*, a cellular siliceous rock, valuable for millstones, as in South Carolina.

Although the Tertiary rocks are generally less firm than those of the Paleozoic, there are in some places hard slates and sandstones, not distinguishable from the most ancient. Such rocks occur in California, in the vicinity of San Francisco ; and it is supposed that some crystalline rocks of the region are altered Tertiary strata.

There are also whitish beds of earthy or chalky aspect, which consist of siliceous Infusoria, and others formed from the shells of Rhizopods.

1. Laramie, or Lignitic Period. — In Mississippi, as shown by Hilgard, a Lignitic group covers a large part of the northern half of the State. It consists in some places at base of small estuary deposits, with marine shells; above these, of clays and sands, with lignite and fossil leaves. He divides it into the *Flatwoods* and the *Lagrange* groups. The two groups continue north through Tennessee into Kentucky, as observed by Safford, who named the former the Porter's Creek group, and the latter, the "Orange Sand" group; the former is mostly clayey in its beds; the latter sandy. The top of the latter contains two or three beds of lignite, and is called by him the "Bluff Lignite;" whole thickness 300 to 400 feet. [Hilgard's "Orange Sand" is Quaternary.]

In the Upper Missouri region, the Lignitic formation has a thickness of 2,000 feet, and lies unconformably beneath the later Tertiary beds. It occurs also in the Big Horn region; in the Chetish or Wolf mountains; about Fort Union. It extends far north into British America, and south to Fort Clarke, and beyond to Texas. In the lower part, on Judith River, there are brackish water deposits, containing shells of *Oysters*, *Corbiculæ*, etc., mingled with fresh-water shells of the genera *Viviparus*, *Melania*, etc. (Figs. 908–913, p. 501). (Meek.)

In the Rocky Mountain region, the Laramie group of the Green River basin, near Fort Bridger, and other parts, in Wyoming, Utah, Colorado, etc., consists of sandy beds, some of them true marine, more of them having a commingling of fresh-water shells with the marine, which indicates very shallow brackish waters. and a still larger part strictly fresh-water in origin; and in these occur various beds of mineral coal. They occur always upturned, and generally at a high angle, along the east foot of the Wahsatch, and adjoining others of the mountain ranges. The coal beds are well seen on Bitter Creek in Wyoming; on Weber and Bear rivers in Utah; in the Green River Basin, north of the Uintah Mountains; in Colorado; New Mexico, etc.

The principal localities where the coal is exposed are — In Utah, at Evanston and Coalville (in the valley of Weber River), etc.; in Wyoming, at Carbon, 140 miles from Cheyenne; at Hallville, 142 miles farther west; at Black Butte Station, on Bitter Creek; on Bear River, etc.; in the Uintah Basin, near Brush Creek, 6 miles from Green River; in Colorado, at Golden City, 15 miles west of Denver, on Ralston Creek, Coal Creek, S. Boulder Creek and elsewhere; in New Mexico, at the Old Placer Mines in the San Lazaro Mountains, etc. The coal is of the bituminous or semibituminous kind. That of Evanston (where the bed is 26 feet thick) afforded Prof. P. Frazier, Jr., 37–38 per cent. of volatile substances, 5–6 of water, 7–8 of ash, and 49–50 of fixed carbon. At the Old Placer mines, New Mexico, there is anthracite, according to Dr. J. LeConte, affording 88 to 91 per cent. of fixed carbon: specimens from there, analyzed by Frazier, were semibituminous, affording 68–70 per cent. of fixed carbon, 20 per cent. of volatile substances, and about 3 per cent. of water. The region of the Old Placer Mines is one of upturned and altered rocks, like the anthracite region of Pennsylvania.

The fact that the Lignitic beds of Mississippi, the Upper Missouri, and the Rocky Mountain region are cotemporaneous, is shown by the identity of several of the species of fossil plants, as made known by Lesquereux. There are also several fresh-water shells of the Upper Missouri region, identical with those of the Green River Basin and elsewhere.

There is a Lignite deposit at Brandon, Vermont, associated with a bed of limonite iron-ore, and abounding in fossil fruits, first described by E. Hitchcock. The plants, according to Lesquereux, are of the same period with those of the Mississippi, Tennessee and Arkansas Lower Lignite beds.

2. Eocene Tertiary. — In the Rocky Mountains the subdivisions are as follows, beginning below: (1) The *Wahsatch* group (*Coryphodon* beds of Marsh, see Plate XII.), including the Vermilion Creek (5,000 feet thick) and Bitter Creek beds, and others in New Mexico, which resemble the Laramie beds, but overlie them unconformably; (2) The *Green River* group, consisting of shales containing fossil fishes, plants, insects, but no Mammals, and perhaps not newer than the Wahsatch; the Elko group is related to it; (3) The *Bridger* group (*Dinoceras* beds of Marsh), in the Green River Basin, overlying the last, and abounding in remains of Mammals (with the Green River beds about 5,000 feet thick); (4) The *Uinta* group, to the south of the Uinta Range, 400 feet thick (the *Diplacadon* beds of Marsh), occupying a small Eocene lake-basin in White River Valley.

The marine Eocene Tertiary of the Alabama Period. — The *Claiborne* beds at Claiborne, Alabama, or the lower of the marine Eocene, consist, beginning below, of (1) Clay, 25 feet, overlaid by a bed of *lignite*, 4 feet; (2) Marl with Oysters (*O. sellæformis* Con.); (3) Marly arenaceous limestone; (4) Marl with Oysters; (5) Sand with shells, partly showing a beach origin, often called the "Orange-sand" group in the region. Whole thickness, about 125 feet.

In Mississippi, there are (1) the Siliceous Claiborne beds, sandstones and clayey layers, near the middle of the western half of the State, 150 feet thick; (2) 60 feet of marlytes and limestone; (3) 80 feet of similar beds, best shown near Jackson, Mississippi, and sometimes separated as the *Jackson group;* (4) 12 feet of Red Bluff beds, black lignitic clays. Then follow 120 feet of beds of the Vicksburg series, or Upper Eocene. (Hilgard.)

The Claiborne beds are locally lignitic, a feature which increases westward in Arkansas, but diminishes eastward in Alabama; and Hilgard considers it as proving that the conditions under which the bottom lignitic beds (No. 1) were formed, continued on, intermittingly, into the following part of the Tertiary era.

The beds at Jackson are (1) *Lignitic* clay; (2) White and blue marls, the former often indurated, with numerous marine shells and remains of the *Zeuglodon.* They cross the State as a narrow band, running east-southeast through Scott and Jackson counties. Whole thickness, 80 feet. (Hilgard.)

The beds of the *Vicksburg* epoch, or Upper Eocene, as represented at Vicksburg, Miss., are (1) *Lignitic* clay, 20 feet; (2) Ferruginous rock of Red Bluff, with numerous marine fossils, 12 feet; (3) Compact limestones and blue marls, with marine fossils, often called the *Orbitoides limestone*, 80 feet: in all, 112 feet. A narrow band crosses the State just south of the Jackson beds, from Vicksburg on the Mississippi. These are overlaid by 150 feet of the "*Grand Gulf*" group of clay, sandstone, and loose sand, with some gypsum, occurring about Grand Gulf, on the Mississippi, and elsewhere south of the latitude of Jackson and Vicksburg, covering the larger part of the southern portion of the State. (Hilgard.)

The Vicksburg group is met with in Alabama, in Monroe, Clarke, and Washington counties, and constitutes a limestone bluff at St. Stephens on the Tombigbee, and limestone at Tampa Bay, Florida.

Near Charleston, S. C., the oldest Eocene there displayed includes (1) Buhrstone beds, 250 feet; (2) White limestone and marls, called the Santee beds. A buhrstone of the same age occurs also in Georgia and Alabama; and the siliceous beds at Claiborne are of the same horizon. This group is represented also near Fort Washington, Piscataway, and Fort Marlborough, in Maryland, and on the Pamunkey at Marlbourne, mostly by dark green sands; and in New Jersey, at Squankum, etc.

The Vicksburg epoch is represented in South Carolina by gray marl, on the Ashley and Cooper rivers, abounding in Rhizopods; and, adding the Santee beds, the whole thickness is 600 to 700 feet.

Yorktown Period, or Miocene. — The Miocene beds cover a large part of the

Atlantic Tertiary Border, occurring at Gay Head, on Martha's Vineyard; in New Jersey, in Cumberland County and elsewhere; and fossils may be collected in the Marl pits of Shiloh, Jericho, etc.; in Maryland, at St. Mary's, Easton, etc.; occurring on both sides of the Chesapeake for a great distance; in Virginia, at Yorktown, Suffolk, Smithfield, and through the larger part of the Tertiary region.

The strata at Yorktown, beginning below, are (1) Clay filled with *Turritella alticostata* Con., *Callista* (*Cytherea*) *Sayana* Con., etc.; (2) Sand, with few shells, chiefly *Yoldia* (*Nucula*) *limatula;* (3) a sandy bed, made up mostly of *Crepidula costata*, Mort.; (4) coarse ferruginous sand. Two miles off, the layer of *Turritellæ* has changed to a layer of *Crepidulæ;* and the continuation of the *Crepidula* layer is filled with *Pectens*, *Venus difformis*, *Ostrea*, etc.

At a locality on James River, Va., there are (1) a layer of shells of *Pecten* and *Ostrea*, 5 feet; (2) bed of *Chamæ*, 3 feet; (3) bed of *Pectens*, with *Ostreæ*, 1 foot; (4) second bed of *Chamæ*, with *Striarca centenaria* Con., *Panopæa reflexa* Say, 6 feet; (5) bed of large *Pectens*, 2 feet; (6) closely compacted bed of *Chamæ* and *Venus difformis*, 3 feet; (7) sand and clay, separated from the preceding by a thin layer of pebbles. But in other localities of the same region, the beds are different. The first layer over the Eocene often consists of pebbles or coarse sand.

One of the most remarkable deposits in the Virginia Tertiary is a bed of Infusorial remains, occurring near Richmond. It is in some places thirty feet thick, and extends from Herring Bay on the Chesapeake, Md., to Petersburg, Va., or beyond, and is an accumulation of the siliceous remains of microscopic organisms, mostly Diatoms. Some of the beautiful forms are represented, much magnified, in Fig. 882, on the next page. These beds have been referred both to the Miocene and to the Eocene; they are called Eocene by Professor Rogers, after an examination of the region.

A still thicker bed — exceeding fifty feet — exists on the Pacific, at Monterey; the bed is white and porous, like chalk, and abounds in siliceous organisms. (Blake.)

The fresh-water beds of the older Miocene, in the Upper Missouri region, along the White River (a region called the "Mauvaises Terres," or Bad Lands), constitute the *White River group* of Hayden, and have a thickness of 1,000 feet or more. The lower beds contain the *Brontotherium*; the higher are the *Oreodont* beds. Still higher fresh-water Miocene occurs in Oregon, which have afforded *Miohippus* and other species.

There are also, in the Wind River valley, and on the west side of the Wind River mountains, other fresh-water deposits, 1,500 to 2,000 feet thick, called the *Wind River* group, which may be of the same age as the White River group. (Meek and Hayden.)

In California and Oregon, marine beds referred to the Miocene consist of sandstone and shale, and are in some places 4,000 to 5,000 feet thick. They occur near Astoria, on the Columbia River and the Willamette; in the Coast ranges of California, north and south of San Franciso, and also in the Contra Costa hills, just east; in the Santa Inez mountains, some points in which are 4,000 feet in height; along the flanks of the Peninsula range, in the latitude of San Diego, etc. Both north and south of San Francisco, on the coast, there are metamorphic slates, part of which are referred by Whitney to the Tertiary.

Sumter Period, or Pliocene. — The beds referred to the Pliocene occur in North and South Carolina, extending south as far as the Edisto River. They contain forty to sixty per cent. of living species of shells. (Tuomey & Holmes.) The beds are soft, either loam, clay, or sand, and lie in depressions of the older Tertiary and Cretaceous formations. The equivalents of these beds in Virginia and New Jersey are not clearly made out; neither are they known from the Gulf States.

In the Upper Missouri region, the White River group is overlaid by other fresh-water Tertiary beds, 300 to 400 feet thick, called by Meek & Hayden the *Loup River* group, and by Marsh the *Niobrara*. They contain in their upper part the remains of numerous extinct Mammals, including Camels, Rhinoceroses, Elephants, Horses, etc., besides land and fresh-water shells which are probably of recent species. These beds occur on the Loup Fork of the Platte, north to the Niobrara, and south nearly to the Gulf.

Phosphatic Deposits on the South Carolina Eocene beds. — The Eocene of South Carolina, about Charleston, and in other portions of the coast region, is thickly covered with

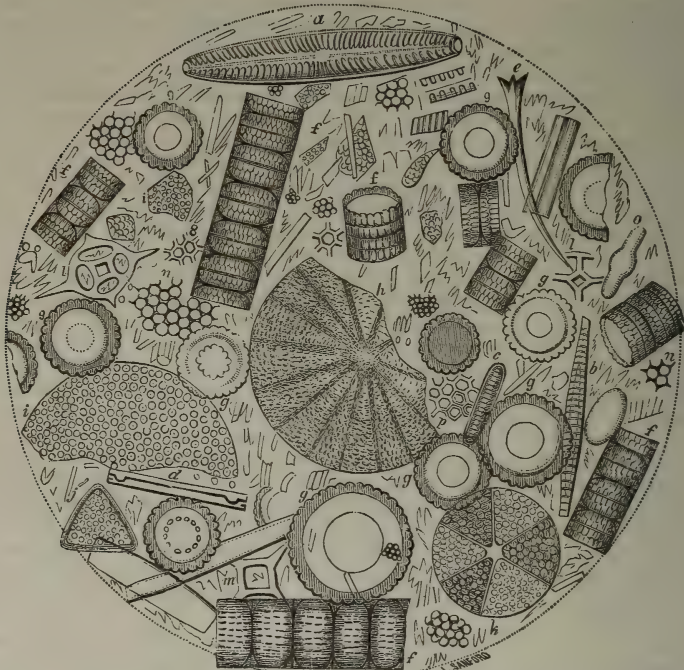
phosphatic deposits, partly nodular in structure, and often containing Eocene fossils. Their origin is explained, by Prof. C. U. Shepard, by supposing that the Eocene beds were covered by extensive guano deposits, and that the percolating waters, carrying down carbonic acid and soluble phosphates, decomposed and carried off part of the Eocene, and altered other portions to phosphates, just as has happened on the Guano islands of the Caribbean sea, where underlying corals and shells are converted into phosphate of lime by a similar process.

II. Life.

1. *Plants.*

1. *Protophytes.* — About one hundred species of Diatoms have been described by Ehrenberg and Bailey, from the Infusorial stratum of

Fig. 882.



Richmond Infusorial Earth. — *a*, Pinnularia peregrina; *b*, *c*, Odontidium pinnulatum; *d*, Grammatophora marina; *e*, Spongiolithis appendiculata; *f*, Melosira sulcata; *g*, transverse view, id.; *h*, Actinocyclus Ehrenbergii; *i*, Coscinodiscus apiculatus; *j*, Triceratium obtusum; *k*, Actinoptychus undulatus; *l*, Dictyocha crux; *m*, Dictyocha; *n*, fragment of a segment of Actinoptychus senarius; *o*, Navicula; *p*, fragment of Coscinodiscus gigas.

Richmond, besides a few Polycystines (siliceous Foraminifers) and many sponge-spicules. Fig. 882 represents a portion of the Richmond earth, as it appeared in the field of view of Ehrenberg's microscope. This is an example of one of the many Infusorial earths of the era.

2. *Angiosperms, Conifers, Palms.* — The Lignitic and coal-bearing

strata, at the bottom of the Eocene, have afforded large numbers of leaves of plants, in Mississippi, Arkansas, the Upper Missouri, and in the coal-bearing series of Wyoming, Utah, Colorado, and other parts of the Rocky Mountain region; others have been obtained, together with a variety of nuts, from a bed of Lignite at Brandon, Vt. Among the plants, there are species of *Plane-tree*, *Oak*, *Poplar*, *Maple*, *Hickory*, *Dog-wood*, *Magnolia*, *Cinnamon*, *Fig*, *Conifers*, *Palms*, etc. Palm-leaves have been found as far north as the Upper Missouri region; one of them, of the Fan-palm family, — a species of *Sabal*, — when entire, must have had a spread of twelve feet.

Figs. 883–887.

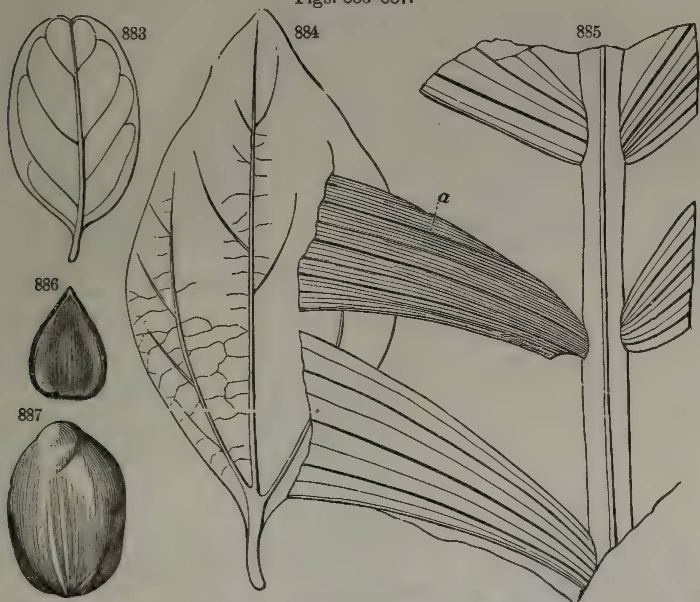


Fig. 883, Quercus myrtifolia (?); 884, Cinnamomum Mississippiense; 885, Calamopsis Danæ; 886, Fagus ferruginea (?); 887, Carpolithes irregularis.

The plants of the beds of Mississippi, the Upper Missouri and other localities mentioned, are closely related to those of the present era.

Among the genera of the older Laramie group, distinguished by Lesquereux and Newberry, are (1) Angiosperms, — *Quercus*, *Carya*, *Populus*, *Acer*, *Ulmus*, *Morus*, *Carpinus*, *Fagus*, *Juglans*, *Betula*, *Alnus*, *Corylus*, *Ilex*, *Negundo*, *Platanus*, *Sapindus*, *Ficus*, *Cinnamomum*, *Laurus*, *Benzoin*, *Persea*, *Myrica*, *Salisburia*, *Cornus*, *Ceanothus*, *Viburnum*, *Rhus*, *Olea*, *Rhamnus*, *Magnolia*, *Smilax*, *McClintochia* (an Arctic genus), *Eucalyptus* (an Australian genus); (2) Conifers, — *Thuia*, *Thuyites*, *Sequoia*, *Abies*, *Taxodium*, *Glyptostrobus*; Palms, — *Sabal*, *Calamopsis*, *Flabellaria*. The genera are mainly those characteristic of North America at the present time.

Golden, Colorado, has afforded the European Eocene species *Sphenopteris Eocenica* Ettingshausen, of Mount Promina, Europe, *Quercus angustiloba* A. Brngt., of the

Bornstädt Eocene; and Black Butte, *Myrica Torreyi*, closely like one of Mount Promina, *Flabellaria latania* Hooker, and *F. Eocenica* A. Brngt. The same beds that afforded the Dinosaurian remains, described by Cope, contain the plants *Sabal Campbelli* Newb. and *Platanus Raynoldsii* Newb., which are found at three or four other localities of the same coal series, along with *Ficus corylifolius* Lsqx., *Laurus obovata* Weber, and *Viburnum dichotomum* Lsqx., not yet observed elsewhere (Lesquereux). The Mississippi beds contain the following Rocky Mountain species, *Flabellaria Zinkeni* Heer, *Populus Arctica* Heer (an Arctic species), *Quercus chlorophylla* Ung., *Laurus pedata* Lsqx., *Cinnamomum affine* Lsqx., *C. Mississippiense* Lsqx., *Magnolia Hilgardiana* Lsqx., *M. Lesleyana* Lsqx., and *Juglans appressa* Lsqx. (Lesquereux) The Rocky Mountain region has afforded the following Arctic species, *Sequoia Langsdorfii* Br., *Phragmites Œningensis* A. Brngt. (Miocene, in Europe), *Populus decipiens* Lsqx., *P. lancifolia* Heer (Miocene, in Europe), *P. Zaddachi* Heer, *Salix Grœnlandica* Heer, *Alnus Kefersteinii* Göpp. (Miocene, in Europe), *Quercus Lyellii* Heer (Miocene, in Europe), *Q. platania* Heer, *Q. drymeja* Ung. (Miocene, in Europe), *Q. Wyomingiana* Lsqx., *Q. Olafseni* Heer, *Q. Laharpi* Göpp., *Corylus Mc Quarryi* Heer, *Fagus Deucalionis* Ung. (Miocene, in Europe), *Ficus tiliæfolia* A. Brngt. (Miocene, in Europe), *Platanus Gulielmæ* Göpp. (Miocene, in Europe), *Platanus aceroides* Göpp. (Miocene, in Europe), *Cinnamomum Scheuchzeri* Heer (Miocene, in Europe), *Andromeda reticulata* Heer, *A. vaccinifolia* Ung., *Viburnum Whymperi* Heer, *Vitis Olriki* Heer, *V. Islandica* Heer, *Magnolia Inglefieldi* Heer, *McClintochia Lyellii* Heer, *Paliurus Colombi* Heer, *Zizyphus hyperboreus* Heer, *Rhus bella* Heer, *Juglans acuminata* (?) Heer (Miocene, in Europe). Lesquereux, from whom this catalogue is taken, thus shows a close relation between the floras of the Arctic and of more temperate latitudes, as well as a relation to the European *Miocene* flora. The latter fact seems to imply that the migration was from America to Europe, as the European species existed in Europe only after their first appearance in America. Lesquereux refers three of the above species exclusively to what he regards as a later division of the Eocene than the others: all the others are found in his Lower division. To the later, he refers the Rocky Mountain localities at Washakie Station, Carbon Station, Evanston, Sage Creek, etc., in Utah: and to the older, the localities of the Raton Mountains, Golden, Denver, etc., in Colorado; Black Butte, Wyoming; Fort Ellis and Elk Creek, Montana; Fort Union, in New Mexico; and in Mississippi.

Fig. 883. *Quercus myrtifolia* Willd. (?), from Somerville, Tennessee, the Lagrange group of Safford; Fig. 884, *Cinnamomum Mississippiense* Lsqx., from Mississippi, northern Lignitic group, at Winston; Fig. 885, *Calamopsis Danæ* Lsqx. ,from Mississippi, northern Lignitic group, in Tippah, Lafayette, Calhoun; Fig. 886, nut of *Fagus ferruginea* Michx. (?) from the Lagrange group of Tennessee; Fig. 887, *Carpolithes irregularis* Lsqx., from the Brandon Lignite bed; Fig. 888, *Carpolithes Brandonensis* Lsqx., the most abundant of the Brandon nuts, natural size. The kind of plant producing these two fruits is undetermined. Among the other Brandon fruits, Lesquereux has recognized the genera *Carya*, *Fagus*, *Aristolochia*, *Sapindus*, *Cinnamomum*, *Illicium*, *Carpinus*, and *Nyssa*. (Amer. Jour. Sci., II. xxxii. 355.)

Fig. 888.

Carpolithes Brandonensis.

The plants of the Lignite bed of Lauderdale (which is distinctly overlaid by the Claiborne Eocene) "show the greatest affinity with species of our time, and are apparently of as recent an epoch as the fruits of Brandon." (Lesquereux.)

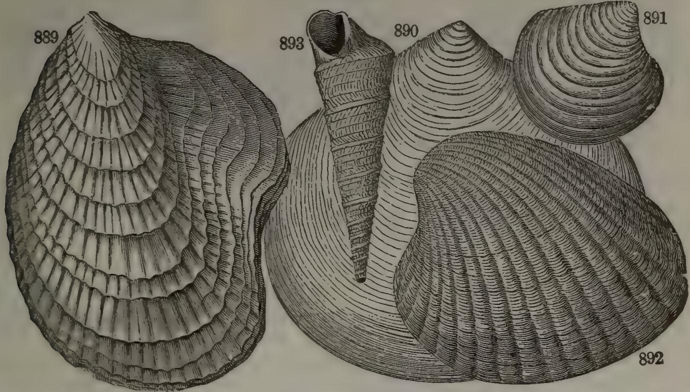
In the beds of the Middle or Upper Eocene, in the Green River or Fort Bridger basin, overlying unconformably the Lignitic Series (referred by Lesquereux to the Miocene, but by Marsh and Cope to the Eocene), there have been found, according to Lesquereux, species of *Sabal* (palm), *Taxodium*, *Salix*, *Myrica*, *Quercus*, *Ficus*, *Platanus*, *Laurus*, *Eucalyptus*, *Ilex*, *Ceanothus*, *Juglans*, *Carya*,

Arundo, Carex, Cyperites, Cyperus, and Poacites. Of the species, *Arundo Gœpperti* A. Brngt., *Salix angusta* A. Brngt., *Platanus Gulielmœ* Göpp., *Juglans Schimperi* Lsqx., *J. denticulata* Heer, are reported as occurring also in the Lignitic series.

2. *Animals.*

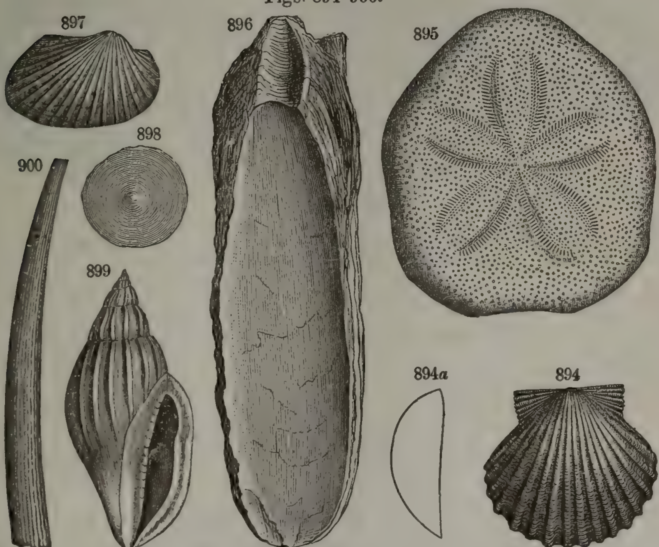
1. Invertebrates.—Among *Protozoans*, Rhizopods are very numerous in some of the beds, as in the Ashley Eocene, in South

Figs. 889–893.



Eocene, Claiborne Group.—Fig. 889, Ostrea sellæformis; 890, Crassatella alta; 891, Astarte Conradi; 892, Cardita planicosta; 893, Turritella carinata.

Figs. 894–900.



Eocene, Vicksburg Group.—Fig. 894, Pecten Poulsoni; *a*, section of same; 895, Mortonia Rogersi; 896, Ostrea Georgiana (× ¼); 897, Anomalocardia Mississippiensis; 898, Orbitoides Mantelli; 899, Cithara Mississippiensis; 900, Dentalium Mississippiense.

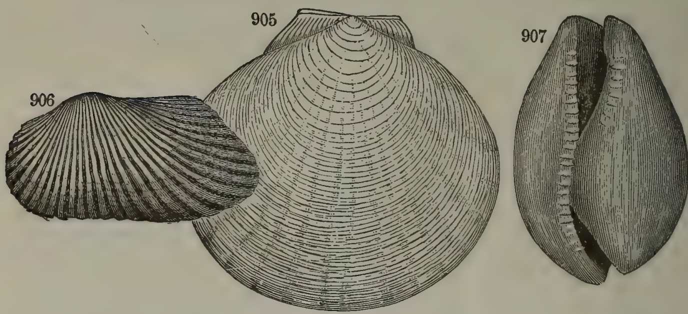
Carolina. The coin-shaped fossils, *Nummulites* and *Orbitoides*, especially species of the latter, abound in the Vicksburg beds; and one species is represented in Fig. 898.

Figs. 901–904.

MIOCENE, YORKTOWN GROUP.—Figs. 901, 902, Crepidula costata. LAMELLIBRANCHS.—Fig. 903, Yoldia limatula; 904, Callista Sayana.

The *Radiates* comprised Polyps and Echini, partly of modern genera. The Mollusks embraced species of *Oyster*, *Venus* (Clam), *Chama*,

Figs. 905–907.



PLIOCENE, SUMTER GROUP.—Fig. 905, Pecten (Amusium) Mortoni; 906, Arca (Scapharca) hians. GASTEROPOD.—Fig. 907, Cypræa Carolinensis.

Arca, *Voluta*, *Cypræa* and other modern genera, but no Brachiopods except *Terebratulids* and *Discinæ*, and no Cephalopods having chambered shells but those of *Nautilus*. There are numerous land and fresh-water shells in the beds of the Upper Missouri region.

Some of the species of the Middle Eocene (Claiborne group) are represented in Figs. 889 to 893; others, of the Upper Eocene (Vicksburg group), in Figs. 894 to 900.

Others, of the Miocene and Pliocene, in Figs. 901 to 907.

Of *Articulates*, there were Crabs and Insects, of all the modern tribes.

The above remarks on the animal life relate only to the Middle Eocene and later species. The Lignitic beds, or Lower Eocene, of the Rocky Mountain region and the Pacific Border are remarkable for combining, along with species of a true Tertiary character, others that are characteristically Cretaceous, owing to the fact that the Cretaceous strata pass up without break or marked transition into the Lignitic Tertiary. These Cretaceous and Cretaceous-like species include *Ino-*

Figs. 908–913.

LAMELLIBRANCHS. — Figs. 908, 908 *a*, Corbula (Potamomya) mactriformis; 909, Cyrene (Corbicula) intermedia; 910, Unio priscus. GASTEROPODS. — Fig. 911, Viviparus retusus; 912, Melania Nebrascensis; 913, Viviparus Leai.

ceramus problematicus (Fig. 837, p. 461), and other allied species, which occur at various levels, through thousands of feet of rock, and are abundant in some beds. In California, an *Ammonite* continues to the top of the Lignitic series. Another peculiarity, already alluded to, is the abundance of fresh-water shells in some beds. Some of these fresh-water species, from the upper Missouri region, are represented in Figs. 908 to 913.

II. VERTEBRATES. — The Laramie beds have not yet afforded any remains of Mammals, and no Vertebrate remains excepting those of Fishes and Reptiles. Saurians occur in it, related to the *Dinosaurs;* and this is the strong Cretaceous feature of the beds.

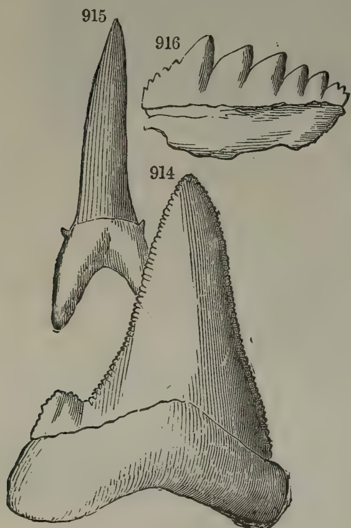
1. *Fishes.* — The remains of Ganoid fishes, (genera *Lepidosteus*, *Amia*), and Teliosts (*Clupea*), are abundant in the Green River shales, which underlie the Bridger beds, along with remains of Plants and Insects; and a few teeth of Sharks have been found in the New Mexico Eocene. The Marine Tertiary beds of the Gulf and Atlantic border, and especially of the Eocene, contain, in many places, shark's teeth in great numbers; three kinds are represented in the accompanying figures. Some of the triangular teeth of *Carcharodon megalodon* Ag. (resembling Fig. 914), are 6 inches broad at base and $6\frac{1}{2}$ long.

2. *Reptiles.* — Species of Crocodiles (among them, *Crocodilus Elliottii* Leidy, from South Carolina), of Snakes (of genus *Dinophis* Marsh, from New Jersey, *Boavus* and *Lithophis*, from Fort Bridger), some twenty feet long, and of Turtles (several species of *Testudo*, *Emys*, etc.), from the Atlantic border and the Rocky Mountain region.

3. *Birds.* — The Eocene and Miocene have afforded remains of species related to Waders, an Owl, a bird near the Woodpecker, some web-footed species allied to the Gannet; and the Pliocene, remains of a large Eagle, a Cormorant, and other kinds. The *Diatryma gigantea* Cope, from the early Eocene of New Mexico, was larger than the Ostrich.

4. *Mammals.* — Tertiary Mammals frequented in vast numbers the shores of the great fresh-water lakes of the Rocky Mountain area, as is proved by the bones that have been found in the lacustrine deposits.

Figs. 914–916.



Teeth of Sharks: Fig. 914, Carcharodon augustidens; 915, Lamna elegans; 916, Notidanus primigenius.

Fig. 917.

Tooth of Zeuglodon cetoides (× ⅔).

These ancient bone-beds remained almost unknown to science until the year 1847; and now, through the labors of explorers, and the works of Leidy, followed by the memoirs of Marsh, Cope, and others, the number of known species far exceeds that of existing North American Mammals. The Laramie beds contain Cretaceous Saurians (Dinosaurs) but no Mammals; the strata above, commencing with the Wahsatch group, have no Cretaceous Saurians, but abound in Mammals. The abrupt transition remains unexplained.

The *marine* Tertiary of the Continent has afforded remains of but few species of Mammals; for seashores are not their ordinary resort, except for some aquatic kinds.

(1.) *Eocene.* — The marine Eocene beds of the Lower Claiborne

group contain the bones of whale-like animals, between the whale and seal in their relations, one of which — the *Zeuglodon cetoides* — was seventy feet or more in length. The teeth, vertebræ, and other parts of the skeleton, have been found in the States of Mississippi, Alabama, Georgia, and South Carolina; and so abundantly, that many of these Eocene whales were probably stranded together, in a common catastrophe, on that shore of the Mexican Gulf. Some of the vertebræ have a length of a foot and a half, and a diameter of a foot. Fig. 917 represents one of the molar teeth, the *yoke*-like form of which suggested the name *Zeuglodon* (from ζεύγλη, *yoke*, and ὀδούς, *tooth*).

The Mammals, whose remains are most abundant in the fresh-water

Fig. 918.

Tapirus Indicus, the modern Malayan Tapir.

Tertiary of the West, are *non-ruminant* UNGULATES or *Herbivores*, having their nearest kin, among living kinds, in the Tapir, Rhinoceros, Horse, and Peccary (Mexican Wild Boar, of the genus *Dicotyles*).

The *Wahsatch* group, the earliest affording Tertiary Mammals, has been found to be rich in species in Colorado, and also in New Mexico and Wyoming.

Among the kinds, the *Coryphodonts* are of special interest, because of their prototype characters, and the occurrence also of species in the earliest Tertiary beds of Europe. They were about as large as the Malayan Tapir, and had similar shortish legs, but they had none of the special family characters of Tapirs, or of other Ungulates, being in most respects a non-specialized form of Ungulate: having the number of teeth, 44, the full normal number (3 incisors, 1 canine, 4 premolars, and 3 molars, on each side, above and below); having, also, the feet all equal, with the number of toes on each five; and the nose not abnormal in being adapted for mechanical work, as it is in the Tapir, Hog, and Elephant. The canine teeth, however, were prominent, suggesting the Wild Boars on one side and Carnivores on the other.

On Plate VI., Fig. 1 gives the form of the skull, and of the very small brain (*b*); 2, a larger figure of the brain, shows the small size of the anterior or cerebral part as compared with the posterior or cerebellar part; and 3 and 4 represent a fore-foot and hind-foot.

Along with the Coryphodonts existed other kinds (*Helaletes* Marsh, *Hyrachyus* Leidy), that were more Tapir-like, the fore-feet having *four* toes, and the hind *three*, — the first or inner toe being wanting in the former, and the first and fifth in the latter; but the nose and the number of teeth were normal. There were also other animals, related to these last, which were, as made known by Marsh, the earliest representatives, of the Horse family, who has recognized two genera of them, *Eohippus* (meaning dawn-horse), and *Orohippus* (mountain-horse). The latter belongs especially to the Bridger beds, but probably existed also in the Wahsatch. They were about as large as a Fox. They had, in front, four perfect toes (Nos. 2, 3, 4, 5, out of the normal five), and behind, three (Nos. 2, 3, 4), and the ulna and fibula of the legs were free (see Plate X.); but they prove their close relation to the Horse-type in (1) the very deep oblique groove of the astragalus or heel-bone for articulation with the tibia or lower bone of the hind leg; (2) the character of the teeth; (3) the large diastema (or toothless space) in the jaw in front of the premolars; and (4) in the elongated form of the feet. In *Eohippus*, the earliest form, there are rudiments of a fifth toe in front (the inner or first).

The *even-toed* Ungulates (characterized by having the toe No. 4 equal in all its articulations to No. 3, as to both size and strength, so that the two strike evenly together, and by having the number of toes usually two or four — these toes being Nos. 3 and 4, or Nos. 2, 3, 4, 5 (No 5 wanting in the hind foot of the Peccary)) were represented only by species of the Hog family or Suillines (the genera, *Eohyus*, *Parahyus*).

Besides species akin to the Ungulates, there were also TILLODONTS (*Dryptodon* Marsh); MONKEYS, related to the *Lemurs;* CARNIVORES (genera *Oxyæna* of Cope, *Limnocyon* of Marsh, etc.), related somewhat to the Wolf; and the earliest of RODENTS, of the Squirrel type.

In the next, or *Bridger* era, the Ungulates comprised other Tapir-like species (*Palæosyops*, *Hyrachyus*, etc.); Horses of the genus *Orohippus;* and new species and genera of Suillines (*Helohyus*, etc.).

Another group is that of the *Dinocerata* of Marsh. These animals were like Elephants in size, but rather short in legs, and bore on the head three pairs of bony prominences standing out like the bases of horns, one pair severally on the snout, the cheeks, and the forehead, giving the huge beasts a grotesque rather than fierce aspect. In habits they were probably like the Rhinoceros. They had *five-toed* feet like

the Coryphodonts, to which they were somewhat related. The species are referred to three genera: *Uintatherium* of Leidy (named from the Uinta Mountains) and *Dinoceras* and *Tinoceras* of Marsh. On Plate VII., Figs. 1 and 2 show the skull in different positions, and the former also the size of the little brain (*b*); and Figs. 3, 4, a fore-foot and hind-foot. The name *Dinoceras*, from the Greek δεινός, *terrible*, and κέρας, *horn*, alludes to the three pairs of prominences (Figs. 1, 2). In some of the Dinocerata, as the *Uintatherium Leidyanum* of Osborn, Scott and Speir, the prominences are long and look like horns. It is supposed that part, if not all, of them were horn-cores or bases of horns; any not so must have been covered with the hide as in the Giraffe. While thus armed to excess, and probably of great strength, the very small brain shows that they were extremely low in intelligence.

The *Tillodonts* were another group peculiar to the Eocene. In the Wahsatch group occur remains of the earliest species. In the Bridger, there are other kinds; and one genus of them was named *Tillotherium* by Marsh. The name, from τίλλω, *to bite*, alludes to the long incisors or front teeth, which are only two in number, and long, much as in the Beaver (*Castor Canadensis*) and other Rodents, and which give the animals a Rodent-like aspect. The earliest known of the Bridger group of Tillodonts was called by Leidy *Trogosus Castoridens*, in allusion to this resemblance in the teeth; he afterwards identified it with a New Jersey Eocene species, his *Anchippodus riparius*. Fig. 1, on Plate VIII., shows the form of the skull, with the small brain; Fig. 2, a profile view of the same with the lower jaw; Figs. 3, 4, upper and lower molars, and 5, *a*, *b*, the claws.

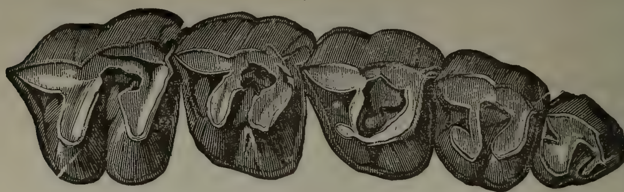
The Bridger era had also monkeys related to the Lemurs, Carnivores related to the *Fox*, the *Wolf*, and the *Cat*, the largest nearly equaling the Lion in size; *Bats*, *Squirrels*, among Rodents; and *Moles* among Insectivores.

The Uinta group, the last of the Eocene, has afforded new Tapir-like species (the *Diplacodon* related to *Palæosyops* of the Bridger group), species of the oldest known genus of the Rhinoceros group (*Amynodon*); and also new *even-toed* Ungulates (*Parameryx*, *Oromeryx*, etc.) that had some relations to the Camels and Stags, and *were the precursors of the true Ruminants.*

(2.) *Miocene.* — The Miocene Mammals were of different species, and mostly of different genera from the Eocene. There were new Tapir-like kinds, some of them referred to the genus *Lophiodon*, which had also European species; new Horses of the genera *Mesohippus*, *Miohippus*, and *Anchitherium*, having but *three* toes in front, and the ulna and fibula not free (Plate X.); several new genera of the Hog

family, among the species of which some of *Elotherium* were as large as a Rhinoceros; Rhinoceroses (of the genera *Rhinoceros*, *Hyracodon*, *Aceratherium*, *Diceratherium*), the molars of one species as in Fig. 919, from Leidy. There were also kinds between the Tapir and Di-

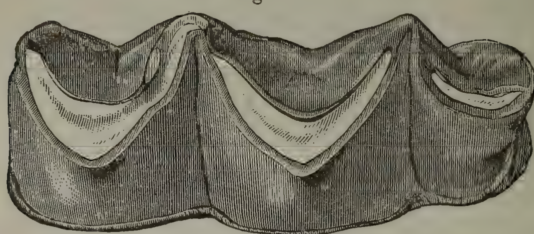
Fig. 919.



Teeth of Hyracodon (Rhinoceros) Nebrascensis.

noceras group, one of them of the genus *Menodus* (*Titanotherium*) was as large as an Elephant; a single tooth half the natural size is represented in Fig. 920. Another kind called *Brontotherium* by Marsh had a pair of horns and was of no less magnitude. As in the Tapirs, it had four toes in front, three behind. (Plate IX.)

Fig. 920.



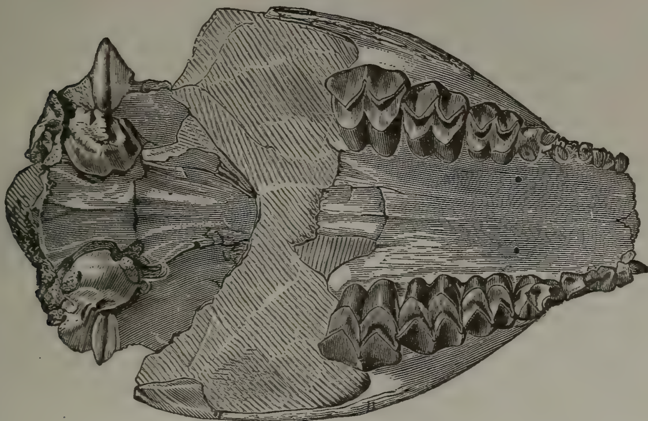
Tooth of Titanotherium Proutii (× ½).

The even-toed Ungulates embraced new Ruminants, the *Oreodonts*, called by Leidy "ruminating hogs," a skull of one of which is represented in Fig. 921, and other kinds more like Stags (*Leptomeryx*) and Camels (*Pœbrotherium*, *Protomeryx*). The Fauna comprised also Carnivores represented by species of *Wolves* (*Canis*, *Amphicyon*), the first of the species of *Machærodus*, a lion with long sabre-shaped canines, species of *Hyænodon*, the largest equaling in size the Black Bear, and several *Insectivores;* and among Rodents, the earliest of American Beavers (*Palæocastor Nebrascensis* Leidy), besides other species.

The Mammals of the Marine Miocene of the Atlantic coast are mainly species of *Whales*, *Dolphins*, *Seals*, and *Walruses*, bones of which have been found at Gay Head on Martha's Vineyard and elsewhere; but also, of *Rhinoceros*, *Lophiodon*, *Elotherium*, from the New Jersey beds, and of *Camelus* from those of Virginia.

(3.) *Pliocene.* — Remains of the Pliocene Mammals that lived about the Great Pliocene Lakes west of the Mississippi are found on the Niobrara and the Loup Fork, the first from which localities were gathered by Hayden, and described by Leidy. They include true Camels (*Procamelus*); *Rhinoceroses*, one as large as the Indian Species; several species of the Horse family of the genera *Protohippus*, and *Pliohippus* (Plate X.); species of Deer, and Musk-Deer; an Elephant, larger than the modern, called *Elephas Americanus*, which continued on into the Quarternary; a Tiger, larger than the Bengal

Fig. 925.



Oreodon gracilis.

Tiger, besides other Carnivores. There was also the first known species for America, of the genus Mastodon (*Mastodon mirificus* Leidy).

The succession of forms under the Horse type is illustrated on Plate X. (from Marsh). This plate contains, in a series of seven columns, figures of (1) the fore-foot; (2) the hind-foot; (3) the lower joint of the fore-leg (made up of the radius and ulna); (4) the same of the hind leg (tibia and fibula); and (5, 6, 7), others showing the length, and the convolutions, of the teeth. Columns 1 and 2 illustrate the fact of the diminishing number of toes, with the progress of the Tertiary, until at last, in the modern kind, only No. 3 (or the middle toe) remains, with rudiments either side of No. 2 and No. 4 (the splint bones), while No. 3 becomes increasingly larger and longer. Columns 3 to 7 illustrate the changes in the limbs and teeth.

Another important fact in the history of life as deduced by Lartet from the early European Mammals, and by Marsh from the American, is the increasing size of the brain with the progress of the Tertiary.

In most of the earliest Eocene species the brain was extremely small, and especially the cerebral or anterior part; that of the Dinoceras might have been drawn entire through the cavity of the spinal cord. This point is illustrated on Plate XI. (from Marsh), representing the skulls reduced to a common length, and the brain cavity, of the Eocene, *Dinoceras* (Fig. 3), the Miocene *Brontotherium* (Fig. 2), and the modern Horse (Fig. 1). The Horse has a brain more than eight times the bulk of that of the Dinoceras. See, also, Fig. 2, Plate VI. It is seen in these figures that the posterior part of the brain, as Marsh observes, has undergone little change of size, the enlargement having been eminently in the cerebral portion. Cope also has recognized similar facts. Moreover, Marsh has shown that the same principle is exemplified in the fossil Birds, and also in the species of the Dinosaur group of Reptiles.

Characteristic Species.

Laramie Period.

1. Radiates. — In the Lignitic coal-bearing bed, south of the Uintah Mountains, Marsh found a Crinoid near the *Marsupites* of the Cretaceous, and in the same vicinity *Ostrea congesta*, and scales of a *Beryx*, other Cretaceous forms. It is at present doubtful whether the beds are Cretaceous or Tertiary.

2. Mollusks. — In the coal-bearing or Lignitic group of the Rocky Mountain region, referred by some to the Cretaceous formation, occur, at different levels (p. 501), *Inoceramus problematicus* and other *Inocerami*, an *Anchura*, *Gyrodes depressa* M., all Cretaceous forms. With these are found *Cardium subcurtum* M., *Avicula gastrodes* M., *Ostrea soleniscus* M., *Cyrena Carltoni* M., *Modiola multilinigera* M., *Neritina pisum* M., *Turritella Coalvillensis* M., *T. spironema* M., *Cyprimera(?) isonema* M., *Eulima funicula* M., *E. chrysalis* M., *E.(?) inconspicua* M., *Melampus antiquus* M., species of *Unio; Corbicula securis* M., *C. æquilateralis* M., *C. fracta* M., *Viviparus trochiformis* M.; also, in some beds in the series, species of the fresh-water genera, *Physa*, *Valvata*, *Cyrena*, *Neritina*, with those of *Melampus*, *Eulima*, *Turritella*, etc.; or of *Goniobasis*, *Viviparus*, *Corbicula*, *Corbula*, along with *Ostrea*, *Anomia*, and *Modiola*. In the fresh and brackish water Lignitic beds of the Upper Missouri region, Figs. 908, 908 *a*, *Corbula* (*Potamomya*) *mactriformis* M. & H.; Fig. 909, *Corbicula intermedia* M. & H.; Fig. 910, *Unio priscus* M. & H.; Fig. 911, *Viviparus retusus* M. & H.; Fig. 912, *Melania Nebrascensis* M. & H.; Fig. 913, *Viviparus Leai* M. & H.

Meek states that the species of *Melampus* differ little from those of the Paris Tertiary Basin; that the species of *Corbula*, *Corbicula*, *Physa*, *Cyrena*, *Neritina*, are very similar to species of the Lower Tertiary in the Upper Missouri region; also that *Viviparus trochiformis* M. is a Tertiary species of the Upper Missouri; while, on the other hand, an *Anomia* is very similar to a Texas Cretaceous species.

In California, in the Tejon group, occur, according to Gabb, species of *Ammonites* (one, *A. jugalis* Gabb), *Fusus*, *Surcula*, *Typhis*, *Tritonium*, *Nassa*, *Pseudoliva*, *Olivella*, *Fasciolaria*, *Mitra*, *Ficus*, *Natica*, *Lunatia*, *Neverita*, *Naticina*, *Scalaria*, *Terebra*, *Niso*, *Cerithiopsis*, *Architectonica*, *Conus*, *Rimella*, *Cypræa*, *Loxotrema*, *Turritella*, *Galerus*, *Nerita*, *Margaritella*, *Gadus*, *Bulla; Solen*, *Corbula*, *Neæra*, *Tellina*, *Donax*, *Venus*, *Meretrix*, *Dosinia*, *Tapes*, *Cardium*, *Cardita*, *Lucina*, *Crassatella* (*C. alta* Con.), *Mytilus*, *Modiola*, *Avicula*, *Arca*, *Axinæa*, *Pecten*, *Ostrea*, with the coral *Trochosmilia striata* Gabb.

3. Fishes, Reptiles. — In the beds of the Upper Missouri, occur scales of *Lepi-*

dotus; remains of Turtles, of the genera *Trionyx, Emys, Compsemys;* species of *Crocodilus,* etc.

Besides these, near Black Butte Station, bones of a Dinosaur, *Agathaumas sylvestre* Cope; and, southeast of the Uinta Mountains, remains of a Saurian related to the *Megalosaurs,* discovered by Marsh; both Cretaceous forms.

4. Mammals. — None yet found.

2. Eocene, after the Laramie Period.

1. Protozoans. — Rhizopods, Fig. 898, *Orbitoides Mantelli* Lyell, Vicksburg group.

2. Radiates. — (*a.*) In the *Jackson Group:* Corals, *Flabellum Warlesii* Con., *Endopachys Maclurii* Lea.; Echinoderms, species of *Scutella, Clypeaster.* (*b.*) In the *Vicksburg Group:* Corals, *Oculina Mississippiensis* Con., *O. Vicksburgensis* Con., *Turbinolia caulifera* Con.; Echinoderms, Fig. 895, *Clypeaster* (*Mortonia*) *Rogersi* Con.

3. Mollusks. — (*a.*) In the *Claiborne Group:* Fig. 889, *Ostrea sellœformis* Con.; *O. divaricata* Lea; *O. vomer; O. panda* Mort.; *Pecten Lyelli* Lea; Fig. 890, *Crassatella alta* Con.; Fig. 891, *Astarte Conradi* D.; Fig. 892, *Cardita planicosta* Sow., from Cañada de las Uvas in California, as well as east of the Mississippi and in Europe (*C. densata* Con.); *C. Blandingii; C. rotunda* Con.; *Cardium Nicolleti;* Fig. 893, *Turritella carinata* Lea; *Calyptrophorus* (*Rostellaria*) *velatus* Con., *Pseudoliva vetusta* Con.; *Orbis rotella* Lea; *Natica Ætites* Con. (Californian, as well as east of the Mississippi); *Anolax gigantea* Lea, *Olivella Alabamensis* Con., *Marginella larvata* Con., *Volutilithes* (*Voluta*) *petrosa* Con., *Corbula gibbosa* Lea; *Nautilites Vanuxemi* Con. (*b.*) In the *Jackson Group* (species common to the Jackson and Vicksburg epochs are marked with a dagger [†]): *Venericardia planicosta* Con.; *V. rotunda*† Lea; *Cardium Nicolleti* Con.; *Corbula bicarinata* Con.; *Leda multilineata* Con.; *Callista sobrina*† Con.; *C. imitabilis* Con.; *Mactra funerata*† Con.; *Psammobia lintea*† Con.; *Navicula lima*† Con.; *Calyptrophorus velatus* Con.; *Cypræa fenestralis* Con.; *C. lintea*† Con.; *C. spheroides*† Con.; *Conus tortilis* Con.; *Gastridium vetustum* Con.; *Mitra Millingtoni* Con.; *M. dumosa* Con.; *Voluta dumosa* Con, *Natica Vicksburgensis*† Con.; *Turbinella Wilsoni*† Con.; *Dentalium Mississippiense*† Con. (*c.*) In the *Vicksburg Group:* Fig. 894, *Pecten Poulsoni* Con.; Fig. 896, *Ostrea Georgiana* Con., one fourth linear dimensions; *O. Vicksburgensis* Con.; Fig. 897, *Anomalocardia Mississippiensis* Con.; *Barbatia Mississippiensis* Con.; *B. Lima* Con.; *Cardium diversum* Con.; *Crassatella Mississippiensis* Con.; *Panopœa oblongata* Con.; Fig. 899, *Cithara Mississippiensis* Con.; Fig. 900, *Dentalium Mississippiense* Con.; also twelve species of *Pleurotomidœ,* four of *Triton,* five of *Mitra,* etc.

One-sixth of the species occur in the Vicksburg beds, and several in the Claiborne. At Red Bluff, there is a stratum between the Jackson and Vicksburg beds, containing many species peculiar to it; twenty-eight per cent. only are Vicksburg species, while six per cent. are Jackson.

4. Vertebrates. — (*a.*) In the *Claiborne Group.* — Fig. 915, *Lamna elegans* Ag.; Fig. 916, *Notidanus primigenius* Ag., from Richmond, Va.

(*b.*) In the *Jackson Group.* — Teeth of Sharks. Fig. 917, tooth of *Zeuglodon cetoides,* natural size.

(*c.*) In the *Vicksburg Group.* — Teeth of Sharks, Fig. 914, *Carcharodon angustidens* Ag.; *C. megalodon* Ag; *Galeocerdo latidens* Ag. — Reptile, *Crocodilus macrorhynchus* Harlan.

(*d.*) In the *Eocene Green-sand beds of Squankum, Monmouth County, New Jersey.* — The sword-fishes, *Histiophorus gracilis* Mh., *Embalorhynchus Kinnei* Mh., *Cœlorhynchus ornatus* L.; the Saw-fish, *Pristis curvidens* L. The Snakes, *Dinophis Halidanus* Mh. (*Palæophis Halidanus* Cope), twenty feet long, *D. littoralis* Mh., *Dinophis grandis* Mh., probably over twenty feet long; the Crocodile, *Crocodilus Squankensis* Mh.; *Gavialis minor* Mh., but six feet long. In South Carolina, *Pristis ensidens* L. In Virginia, *Pristis brachiodon* Cope.

(*e.*) In the *Fresh-water beds of the Rocky Mountain Region, in Wyoming, Utah, and Colorado.*

(1.) FISHES, in the inferior shales, in the Green River group. The Gars, *Lepidosteus glaber* Mh., *L. Whitneyi* Mh., *Amia Newberrianus* Mh., *A. depressus* Mh.; the Teliosts, *Clupea humilis* L., *Clupea pusilla* Cope, *Heliobatis radians* Mh., a land-locked ray.

(2.) REPTILES. — Species of *Emys*, *Trionyx*, etc., among Testudinates; of *Alligator*, *Crocodilus*, *Diplocynodus*, *Limnosaurus*, etc., among Crocodilians; of *Saniva* (of Leidy), *Naocephalus* (of Cope), *Thinosaurus leptodus* Mh. (seven feet long), *Glyptosaurus princeps* Mh. (six feet long), among Lacertilians; *Boavus occidentalis* Mh., probably eight or ten feet long, *B. agilis* Mh., *B. brevis* Mh., *Lithophis Sargenti* Mh.

(3.) BIRDS. — An Owl, *Bubo leptosteus* Mh.; the Woodpecker (?), *Uintornis lucaris* Mh.; the Waders, *Aletornis nobilis* Mh., *A. gracilis* Mh., etc.

The following are some of the described species from the WAHSATCH group. Ungulates: *Coryphodon hamatus* Mh., *C. elephantopus; Helaletes* (*Hyrachyus* Cope) *singularis*, *Eohippus tapirinus* Mh., *E. validus* Mh., *E. pernix* Mh., *Parahyus vagans* Mh. Carnivores: *Oxyæna lupina* Cope. Tillodonts: *Dryptodon crassus* Mh., *Calamodon simplex* Cope. From the BRIDGER group. Ungulates: *Palæosyops paludosus* L., *P. major* L., *P. levidens* Cope, *Telmatotherium validus* Mh., *Limnohyus robustus* Mh., *Hyrachyus agrarius* L., *H. Bairdianus* Mh., *Helaletes boops* Mh., *Orohippus agilis* Mh., *Helohyus lentus* Mh., *Homacodon vagans* Mh., *Amynodon advenus* Mh. (from the Uinta beds), *Uintatherium robustum* L., *U. Leidyanum* Osborn, Scott and Speir, *Dinoceras mirabile* Mh., *Tinoceras anceps* Mh., *Tinoceras grandis* Mh. (*Loxolophodon cornutus* Cope, according to Marsh). Tillodonts: *Tillotherium hyracoides* Mh., *Anchippodus minor* Mh., *Stylinodon mirus* Mh., *Trogosus castoridens* L. Primates allied to the Lemurs: *Lemuravus distans* Mh., *Hyopsodus paulus* L., *H. gracilis* Mh., *Limnotherium tyrannus* Mh., *L. elegans* Mh., *Thinolestes anceps* Mh., *Telmatolestes crassus* Mh. Carnivores: *Mesonyx obtusidens* Cope (size of Wolf), *Limnofelis ferox* Mh. (size of Lion), *Limnocyon riparius* Mh., *Oreocyon latidens* Mh., *Dromocyon vorax* Mh., *Vulpavus palustris* Mh., *Viverravus gracilis* Mh., *Ziphacodon rugatus* Mh. Rodents: *Paramys delicatus* L., *P. leptodus* Cope, *P. robustus* Mh., *Sciuravus parvidens* Mh., *Tillomys senex* Mh., *Colonomys celer* Mh. Insectivores: *Palæacodon verus* L., *Passalacodon litoralis* Mh., *Talpavus nitidus* Mh., *Centetodon pulcher* Mh. Bats: *Nyctitherium velox* Mh., *N. priscum* Mh., *Nyctilestes serotinus* Mh. Marsupials, *Triacodon fallax* Mh., *T. grandis* Mh., *T. aculeatus* Cope.

3. YORKTOWN PERIOD, OR MIOCENE.

1. Mollusks. — In the marine beds of the Atlantic Border. — Fig. 901, *Crepidula costata* Say; Fig. 902, inside view of the same; Fig. 903, *Yoldia limatula* Say, also recent; Fig. 904, *Callista Sayana* Con.; *Pecten decennarius* Con.; *P. Virginianus* Con.; *Cardium Virginianum* Con.; *Venus tridacnoides* Con.; *V. capax* Con.; *Chama corticosa* Con.; *Axinæa tumulus* Con.; *Anomia Ruffini* Con.; also, among living species, *Ostrea Virginiana* Gmelin, or common Oyster; *Venus mercenaria* Lam., or common Clam, *V. cancellata* Gabb, *Mactra* (*Mulinia*) *lateralis* Say; *Pecten concentricus* Say; *Lunatia heros* Stimpson; *Oliva litterata* Lam., *Nassa* (*Tritia*) *trivittata* Say, etc.

In the marine beds of the Pacific Border. — Some of the species of California, as given by Gabb, are *Nassa fossata* * Gould, *Neverita saxea* Con., *Cerithidea Californica* * Hald., *Turritella Hoffmanni* Gabb, *T. variata* Con., *Machæra patula* * Cpr., *Tellina congesta* Con., *Lutricola alta* * Cpr., *Lucina borealis* * Linn., *Yoldia impressa* * M., *Pecten propatulus* Con.; with the Echinoderms *Clypeaster Gabbii* Rém., *Scutella Gibbsii* Rém. The Miocene of Oregon also contains various species.

2. Vertebrates. — FISHES. — On the Atlantic Border. — *Carcharodon megalodon; Galeocerdo latidens* Ag.; *Hemipristis serra* Ag.; *Oxyrhina hastalis* Ag. In the Miocene of Ocoya Creek, California, teeth of Sharks, of the genera *Echinorhinus*, *Scymnus*, *Galeocerdo*, *Prionodon*, *Hemipristis*, *Carcharodon*, *Oxyrhina*, and *Lamna*, besides a tooth of a *Zygobates*. (Agassiz.)

REPTILES. — In the Upper Missouri region. — *Testudo Culbertsonii* L., *T. hemisphærica* L., *T. Oweni* L., *T. lata* L.

BIRDS. — On the Atlantic Border. — *Puffinus Conradi* Mh., in Maryland; *Catarractes*

antiquus Mh , in North Carolina; *Sula* (?) *loxostyla* Cope, in North Carolina. In Colorado, *Meleagris antiquus* Mh., a wild turkey.

MAMMALS. — On the Atlantic Border. — *Balæna prisca* L.; *B. palæatlantica* L.; *Delphinus Conradi* L.; *Phoca Wymani* L., etc.; *Elotherium Leidyanus* Mh., a gigantic species of the Hog family; *Dicotyles antiquus* Mh., a Peccary; *Rhinoceros matutinus* Mh.; *Anchippodus riparius* L.; *Lophiodon validus* Mh.

On the Pacific Border, remains of Cetaceans, etc.

In the Upper Missouri region (White River Group). — Fig. 923, *Titanotherium Proutii* L., one of the teeth, — the last posterior inferior molar, — half natural size. Fig. 924, *Hyracodon Nebrascensis* L., three posterior superior molars, left side, natural size. Fig. 925, *Oreodon gracilis* L., skull, young animal, under side; *Oreodon Culbertsoni* L.; also, according to Leidy, species of the genera *Drepanodon, Hyænodon, Amphicyon, Dinictis,* of Carnivores; *Anchitherium* (*A. Bairdii*), of Solidungulates; *Agriochœrus* (*A. antiquus,* L., *A. major* L., etc.), related to *Oreodon; Pœbrotherium* (*P. Wilsoni* L.), *Leptauchenia, Protomeryx, Merycodus,* of Ruminants; *Rhinoceros, Hyracodon, Lophiodon, Mastodon,* of Sthenorhines; *Chœropotamus, Leptochœrus, Hyopotamus, Elotherium* (*E. Mortoni* L.), and others, of Suillines; *Chalicomys, Ischyromys, Palæolagus, Eumys,* of Rodents.

In the Miocene (White River Group) of Colorado, besides several of the above species, *Brontotherium gigas* Mh., nearly as large as an Elephant, *B. ingens* Mh., still larger, and *Elotherium crassum* Mh., two thirds as large as a Rhinoceros.

In the Miocene of Oregon occur *Oreodon superbus* L., *O. occidentalis* Mh., *Agriochœrus antiquus* L., *Anchitherium Condoni* L., *Rhinoceros Pacificus* L., *R. annectens* Mh., *Dicotyles pristinus* L., etc.

4. PLIOCENE.

1. **Mollusks.** — Fig. 905, *Pecten* (*Amusium*) *Mortoni* Ravenel; *Janira hemicyclica* Ravenel; Fig. 906, *Arca* (*Barbatia*) *hians* Tuomey & Holmes; *A. lienosa* Say; *Sconsia Hodgii* Con.; Fig. 907, *Cypræa Carolinensis* Con.; *C. pediculus* Lam.; *Conus adversarius* Con.; *Fasciolaria rhomboidea* Rogers; *Busycon incile* Conrad. These South Carolina Pliocene beds contain, according to Tuomey & Holmes, nine species of Echinoderms, while none are found in the Yorktown beds in Virginia. Corals are rare in the beds of both the Sumter and Yorktown epochs.

On the Pacific Border, there are many species. They have been described, mostly by Gabb, in a Report connected with Whitney's geological survey of California.

2. **Vertebrates.** — FISH. — *Mylocyprinus robustus* L.

BIRDS. — The Loup Fork beds have afforded a fossil Eagle, *Aquila Dananus* Mh., a Crane, *Grus Haydeni* Mh.; and those of Idaho, a Cormorant, *Graculus Idahensis* Mh.

MAMMALS. — The Loup Fork region, on the Niobrara, has afforded species of Carnivores, of the genera *Felis* (*Felis augustus* L.), *Canis, Leptarctus* (*L. primus* L.), etc.; Sthenorhines, of the genera *Elephas* (*E. imperator* L.), *Mastodon* (*M. mirificus* L.), *Rhinoceros* (*R. crassus* L.), *Dicotyles* (among Suillines); Ruminants, of the genera *Procamelus, Homocamelus, Megalomeryx, Merycodus, Cervus,* etc.; Solidungulates, of the genera *Hipparion* (*H. parvulum* Mh., of the size of a goat, *H. occidentale* L.), *Protohippus, Merychippus, Equus,* etc.; Rodents, of the genera *Castor* (*C. tortus* L.), *Palæocastor, Hystrix.* The *Equus excelsus* L. was quite as large as the modern Horse.

The Oregon Pliocene has afforded the Suillines, *Platygonus Condoni* Mh., and *Dicotyles Hesperius* Mh., besides *Rhinoceros Oregonensis* Mh.

2. FOREIGN TERTIARY.

I. Rocks: kinds and distribution.

The rocks of the Tertiary period in Britain are nearly all Eocene; and the thickness of the beds of this era is over 2,500 feet. Above

the Eocene, there are thin leaf-beds of Miocene age, and about 100 feet of Pliocene. They are most largely developed over the "London basin," covering part of southeastern England. From this region in England, the Eocene spreads southward over the "Paris basin," a portion of northern France, having Paris near its centre. The middle Eocene, of the southern half of Europe and Asia and northern Africa, is remarkable for the abundance of the coin-shaped fossil called *Nummulites* (from the Latin *nummus*, a *coin*), a kind of Foraminifer or Rhizopod secretion, as explained on page 131. Some limestones are almost entirely made of Nummulites. The Nummulitic rocks extend over large parts of the Pyrenean and Mediterranean basins, covering portions of the Pyrenees, the Alps (constituting the summits of the Dent de Midi, 10,531 feet, and of Diablerets, 10,670 above the sea-level), the Apennines, and the Carpathians; they extend into Egypt (where the Pyramids were in part made of Nummulitic limestone); also through Algeria and Morocco, parts of Asia Minor, Persia, Caucasus, India, the mountains of Afghanistan, the southern slopes of the Himalayas, and to a height of 16,500 feet in western Thibet. They occur also in Japan, on Luzon in the Philippine Islands, and in Java.

Later in the Tertiary, the beds were much less generally marine, and more limited in extent, showing an approximation to the existing era, in the condition of the continents. The Miocene had still a very wide distribution over France, Switzerland, Belgium, etc., and is partly marine. It has in Switzerland a thickness of 7,000 or 8,000 feet. The Lower and Upper Miocene are of fresh water, while the Middle is of marine origin. The beds underlie a large part of the region between the Alps and the Juras, and constitute some high summits, as the Rigi, near Lake Lucerne. The Upper division, at Œningen, afforded the famous *Homo diluvii testis* of Scheuchzer (in 1700) — (shown by Cuvier to be an aquatic Salamander), and is noted also for its fossil plants and insects.

In the Pliocene era, there were some marine deposits in Britain. The strata are most largely developed in Sicily, covering nearly half the island, and having in some places an elevation of 3,000 feet above the sea.

The principal subdivisions of the Tertiary, in Britain and Europe, are the following: —

1. Lower Eocene. — (1.) Thanet sands (fluvio-marine), of Britain, containing rolled flints, etc.; the Lower Landenian of Belgium. (2.) Woolwich and Reading beds, of Britain; Upper Landenian of Brussels, Argile Plastique et Lignite, Glauconie Inférieur of France. (3.) London Clay; Lower Ypresian of Belgium.

2. Middle Eocene. — (1.) Lower Bagshot beds; Upper Ypresian of Belgium, Lits Coquilliers and Glauconie Moyenne of France. (2.) Bracklesham beds of Britain; Bruxellian of Dumont, Calcaire Grossier et Glauconie Grossière of France. (Grobkalk,

Germ.) The Suessonian (from Soissons) of D'Orbigny includes part of the Lower Eocene (the London Clay excluded); also a large part of the Nummulitic beds.

3. Upper Eocene. — (1.) Barton Clay, of Great Britain; Lower Læckenian, of Belgium: Lower zone of Sables Moyens, of France. (2.) Upper Bagshot beds, of Britain; Upper Læckenian (?) of Belgium; Upper zone of Sables Moyens, of France. (3.) Osborn and Headon beds, of Great Britain; part of Upper Læckenian (?); Calcaire Marin et Grès de Beauchamp. (4.) Bembridge beds, of Great Britain; Calcaire Siliceux, Calcaire Lacustre Moyen, Gypseous series of Montmartre, of France; Tongrian, of Belgium. The preceding 1 to 4 correspond to the Upper Nummulitic beds, and the upper part of the Flysch, of Switzerland. (5.) Hempstead beds, of Great Britain; Marnes Marines, Grès de Fontainebleau; Rupelian of Dumont.

The Lower Fahlunian of D'Orbigny included the Grès de Fontainebleau, and the Upper, the Miocene. The *Oligocene* of some geologists comprises the preceding sections, 3 to 5, of the Upper Eocene, with the following Lower Miocene. The *Flysch*, of Switzerland, is a thick formation of dark-colored shale and sandstone, overlying Nummulitic beds, and abounding in Fucoids (*Chondrites*); it corresponds to the sections 1, 2, 3 of the Upper Eocene.

4. Lower Miocene. — *Britain.* — Marine and fresh-water Lignites, and Clay of Bovey Tracey; Isle of Mull Leaf-bed and Coal. *Europe.* — Part of Terrain Tertiaire Moyen; Lacustrine of Auvergne; Mayence basin; part of Tile clay near Berlin; Cyrena shale of South Bavaria, characterized by *Cyrena semistriata* Desh.; probably the so-called Miocene of Mayence and Castel-Gomberto; also the fresh-water Molasse of the cantons of Vaud, Berne, and Argovie; Radaboj beds of Croatia; Miocene beds of Greenland.

5. Upper Miocene. — *Britain.* — No marine beds. *Europe.* — *Upper Fahlunian* of D'Orbigny; Fahluns of Touraine; beds of Gironde and Landes; part of Vienna basin; Superga Hill, near Turin; marine Molasse, and Upper fresh-water Molasse, in Switzerland; Siwalik Hills, India.

6. Older Pliocene. — *Britain.* — Coralline Crag and Red Crag of Suffolk, about 100 feet in all. *Europe.* — Subapennine marls and sands; Upper massive beds of Montpellier; Hills of Rome; Mount Mario, etc.; Antwerp and Normandy Crag; part of Upper fresh-water Molasse; Aralo-Caspian deposits.

7. Newer Pliocene. — *Britain.* — Norwich Crag, of fluvio-marine origin, containing mostly shells of species now found in British seas, with some Mammalian remains; Forest-bed of Norfolk cliffs, with *Elephas meridionalis*, etc. *Europe.* — Sicilian Pleistocene formation, which covers nearly half the island of Sicily; near the centre of the island, at Castrogiovanni, it has a height above the sea of 3,000 feet; the upper two thirds of the whole are limestone, and the rest mainly sandstone and conglomerate, underlaid by marl or clay.

The diversity of the beds in the Tertiary period is well shown in the Paris basin formation. There is, *first*, a bed of plastic clay with lignite, containing in some places Oysters (*O. bellovacina*) and a few other marine species, and in other layers lacustrine shells, along with bones of the earliest quadrupeds of the age; *second*, a series of beds of coarse limestone (Calcaire Grossier), with green marls, abounding in some parts in Nummulites and other Rhizopods; containing marine shells (over 500 species in all) in certain beds, a mingling of species of *Cerithium* with fresh-water shells in others, and also bones of Mammals; *third*, over this limestone, a siliceous limestone, containing a few fresh water shells; *fourth*, Gypseous marls, well displayed in the hill of Montmartre, the great repository of the bones of Eocene Mammals, explored by Cuvier, and containing also remains of Birds, Reptiles, and Fishes, with a few fresh-water shells; *fifth*, sandstone, Grès de Fontainebleau, marine in origin, and regarded as of the same age with the lower part of the Molasse of Switzerland; *sixth*, Upper Lacustrine, or fresh-water beds.

In the European Eocene, the fossils are all, or very nearly all, of

extinct species; in the Lower Miocene, nearly all the shells are extinct; in the Upper Miocene, the majority are extinct; in the Older Pliocene, the majority of the shells are of living species; in the Newer Pliocene, Norwich Crag, nearly all the shells are living.

II. Life.

1. *Plants.*

Protophytes were abundant, as in America; the well known Infusorial beds of Bilin, in Bohemia, have a thickness of fourteen feet, and are fresh-water Tertiary. Planitz, in Saxony, is another similar locality.

The higher plants are mainly Angiosperms, Conifers, and Palms.

The Isle of Sheppey is famous for its fossil fruits; and from them Bowerbank has distinguished those of thirteen species of Palms, related to the *Nipæ* of the Moluccas and Philippine Islands, showing that England in the Eocene was a land of Palms. In the Middle Eocene, in England, there were species of Fig, Cinnamon, various *Proteaceæ*, etc., showing that the vegetation was much like that of India and Australia. In the Tyrol, there are other Eocene beds containing Palms; moreover, out of 180 species of plants, 55 were Australian in character, and 23 allied to plants of tropical America. In the Miocene, Palms appear not to have reached so far north as England; and the forests of Europe were less tropical in character. What is remarkable, a much larger proportion of species than now were of North American type, showing that, while the Eocene vegetation of Europe was largely Australian, the second or Miocene phase (including in part at least the Upper Eocene of Lyell) was more like that of North America than now. In the Pliocene, the Flora embraces the modern genera of Rose, Plum, Almond, Myrtle, Acacia, Whortleberry, besides Maples, Oaks, etc.

The Miocene of Greenland, lat. 70°, afforded Heer 162 species of plants, very few of which now live in the region. The number of Arctic species now known is 194, of which 46 are identical with Miocene plants of Europe. They include many kinds of trees — none of which now exist in Greenland or within 10° of it — among them, the yew, *Taxodium dubium* Sternb., the Redwood, *Sequoia Langsdorfii*, Brngt., and several other species of this California genus; also *Alnus Kefersteinii* Göpp., *Fagus Deucalionis* Ung., *Platanus aceroides* Göpp., *Salix macrophylla*, species of the Japan genera *Thuiopsis* and *Salisburia*, besides *Oaks*, *Poplars*, *Walnuts*. There were also a *Magnolia* and a *Zamia*. Spitzbergen, in lat. 78° 56′, has yielded ninety-five species, including two species of *Taxodium*, and species of Hazel, Pop-

lar, Alder, Beech, Plane-tree, and Lime. As Lyell observes, "such a vigorous growth of trees within 12° of the pole, where now a dwarf Willow and a few herbaceous plants form the only vegetation, and where the ground is covered with almost perpetual snow and ice, is truly remarkable."

Eocene plant-beds occur also at Sotzka in Upper Styria, Sagor in Illyria, Monte Cromina in Dalmatia, etc.; others referred to the Miocene epoch exist at Bilin in Bohemia; St. Gallen in Switzerland; Œningen in Germany; at Parschlug, Fohnsdorf, Leoben, Köflach, etc., in Styria; at Swoszowice in Galicia, etc.

Out of 180 species from the Eocene beds of Haring, 55, according to Ettingshausen, are Australian in type, 28 East Indian, 23 tropical American, 14 South African, 8 Pacific, 7 North American and Mexican, 6 West Indian, 5 South European. The resemblance to Australia consists not merely in the number of related species, but in their character, —the small, oblong, leathery-leaved *Proteaceæ* and *Myrtaceæ*, the delicately-branching *Casuarinæ*, the Cypress-like species of *Frenela* and *Callitris*, etc. Only eleven species have their representatives in warm-temperate climates.

In the Miocene of Vienna, nearly a third are North American in type; but with these there are some South American, East Indian, Australian, central Asiatic, and not a sixth European. The species particularly related to those of North America (its warmer portion) belong to the genera *Fagus*, *Quercus*, *Liquidambar*, *Laurus*, *Bumelia*, *Diospyros*, and *Andromedites*.

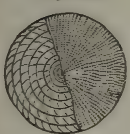
The Pliocene Flora of Europe was strikingly North American in type, as Brongniart has shown. He mentions as examples the following genera of temperate North America, which do not now occur in Europe: *Taxodium*, *Comptonia*, *Liquidambar*, *Nyssa*, *Robinia*, *Gleditschia*, *Cassia*, *Acacia*, *Rhus*, *Juglans*, *Ceanothus*, *Celastrus*, *Liriodendron*, *Symplocos*. Moreover, certain genera, as that of the Oak (*Quercus*), which have numerous species in America, had many in Pliocene Europe, but have *few now*.

In the Alpine Eocene of Bavaria, Gumbel has found clay-beds full of Coccoliths, with Foraminifers.

2. *Animals.*

The shells of Rhizopods, *foraminifers*, were as important and abundant in the Eocene Tertiary as in the Cretaceous period. Among them, the coin-shaped *Nummulites* contributed very largely to the constitution of some of the Middle Eocene strata, as already stated (p. 512). A common species is here represented, with the exterior of half of it removed, so as to show the spiral ranges of cells that were formed by successive budding of Rhizopods.

Fig. 926.



Nummulites nummularia.

Mollusks were far more numerous in species and individuals in Europe than in North America. The shells of some localities — as, for example, the Paris basin — often have nearly the freshness of living species, excepting a prevalence of a white color, the original tints being mostly lost. There are few Brachiopods (about a fifth as many as in the Cretaceous); and these are almost all of the groups of *Terebratulids* and *Rhynchonellids*.

The *Vertebrates* are the species of highest interest. The order of

Teliosts, or common fishes, which began in the Cretaceous, was profusely represented; their numbers exceeding much those of Ganoids. Teeth of *Sharks* are also common, and are like those of America in genera and partly in species.

Among Reptiles, there were many true *Crocodiles*, — eighteen or twenty species having been described. Over sixty species of Turtles are known; and the shell of one Indian species, of the Miocene — *Colossochelys Atlas* Falconer & Cautley — had a length of twelve feet, and the animal a total of nearly twenty feet. The feet must have been larger than those of a Rhinoceros.

A species of Snake, twenty feet long, *Palæophis typhæus* Owen, was discovered in the Bracklesham beds of the Middle Eocene, and another species, thirteen feet long, in the Lower Eocene of Sheppey. Several species related to the common Black Snake (*Colubridæ*) occur in the Miocene.

Remains of a large number of Tertiary Birds have been found and described. According to A. Milne Edwards, the Miocene beds of the Department of Allier, in central France (between 46° and 47° in latitude), has alone afforded seventy species; and many of these Miocene birds are of tropical character. He says, respecting them—Parrots and Trogons inhabited the woods. Swallows built, in the fissures of the rock, nests in all probability like those now found in certain parts of Asia and the Indian Archipelago. A Secretary Bird, nearly allied to that of the Cape of Good Hope, sought in the plains the serpents and reptiles which at that time, as now, must have furnished its nourishment. Large Adjutants, Cranes, and Flamingoes, the *Palælodi* (birds of curious forms, partaking of the characters both of the Flamingoes and of ordinary Grallæ) and Ibises frequented the banks of the watercourses, where the larvæ of insects and mollusks abounded; Pelicans floated in the midst of the lakes; and, lastly, Sand-grouse and numerous gallinaceous birds assisted in giving to this ornithological population a strange physiognomy, which recalls to mind the descriptions that Livingstone has given us of certain lakes of southern Africa.

The London Clay (Eocene) has afforded Owen *a bird with teeth*, named by him *Odontopteryx*, but having the teeth simply dentations of the bony edge of the bill.

Among the *Mammals*, the earliest, or those of the *lower* Eocene in England, are Pachyderms, related to the Tapir, of the genera *Lophiodon*, *Coryphodon*, and *Hyracothere*, and a dog-like Carnivore, the *Palæocyon* of Owen. They were found in the London Clay. In France, beds supposed to be still lower, or equivalent of the bottom beds of the Eocene, have afforded, at La Vère, in the department of Aisne, a

bear-like Carnivore, the *Arctocyon primævus* Blv.; and this is, as yet, the earliest of known Tertiary Mammals. But the greater part of Eocene Mammalian remains belong to the Tapir group.

The earliest discoveries were made by Cuvier. The bones were gathered in the vicinity of Paris, from the Middle and Upper Eocene; and a large number of extinct quadrupeds came to a new existence through his researches. Among those of the Middle Eocene, the *Paleothere* (named from παλαιός, *ancient*, and θήριον, *wild beast*), related to the Tapir in its elongated nose and other respects, is one of the most characteristic. The largest species of the genus, *Palæotherium magnum* Cuv., was of the size of a horse, and a smaller, *P. curtum*, Cuv., not larger than a sheep. The *P. magnum*, as restored by Cuvier, had the stout form of the Tapir; but a skeleton, discovered in 1874, referred to this species, has the long neck, and nearly the figure, of a Lama.

With the *Paleothere*, there existed other tapir-like beasts, of the genus *Lophiodon*, and others.

In the Upper Eocene of Paris, occur the remains of *Anoplotheres* and *Xiphodons*, a group related to the Ruminants in their two toes, but

Fig. 927.

Xiphodon (Anoplotherium) gracile, as restored by Cuvier.

at the same time having some characters of the Hogs; the Xiphodons were of slender form (Fig. 927). The species were remarkable for having the set of teeth as even in outline as in Man, the eye-tooth having nothing of the elongation common in brutes and a striking part of the armature of Hogs and Carnivores, and hence its name, from ἄνοπλος, *unarmed*, and θήριον. The number of teeth is forty-four, the complete series, it including, in either half of either jaw, three incisors, four præmolars, or milk teeth, and four molars. With the *Anoplothere*, a related but still more hog-like kind was the *Chæropotamus*. There were also *Paleotheres* and others of the Tapir tribe; and,

with these, various Carnivores, Rodents, Bats, and an Opossum, one of the Marsupials. The Carnivores included a Wolf, *Canis Parisiensis*, the weasel-like *Cynodon Parisiensis*, the dog-like *Hyænodon dasyuroides*, etc. Remains of about fifty species of quadrupeds have been found in the Paris Eocene.

In the Miocene, there were *Mastodons*, *Elephants*, and the still stranger Elephantine animal, the *Dinothere*. besides Paleotheres and other Tapir-like beasts, new Carnivores, Monkeys, Deer, and the first *Edentates*, but, as far as yet found, none of the Bovine or Ox kind.

Fig. 928 represents the skull of the *Dinothere* (*Dinotherium giganteum* Kaup), much reduced. The head carried a trunk, like an Elephant, and two tusks; but the tusks were turned downward. The length of the skull is three feet eight inches. The jaws have on each side five molar teeth, the first two answering to the posterior præmolars. There is a mixture of the characteristics of the Elephant, Hippopotamus, Tapir, and the marine Manatus (Dugong), in its skull. One fine skull was dug up at Epplesheim in Germany; and the remains have also been found in France, Switzerland, and a few other regions.

Fig. 928.

Dinotherium giganteum ($\times\frac{1}{40}$).

As the Sloth tribe is now confined to other continents, it is an interesting fact that, in the course of the Miocene, Europe had its species, the *Macrothere*, which was related to the African Pangolin (the Ant-eater), but was six or eight times its size.

All the Fishes, Reptiles, Birds, and Mammals of the Tertiary are extinct species.

Characteristic Species.

Lower Eocene of England. — Thanet sands. — *Pholadomya cuneata* Sow., *Cyprina Morrisii* Sow., *Corbula longirostris* Desh., *Scalaria Bowerbankii* Morr.

Woolwich and Reading beds. — *Cyrena cuneiformis* Fer., *C. tellinella* Fer., *Melania inguinata* Dfr., *Ostrea bellovacina* Lam.

London Clay (Island of Sheppey, etc). — *Nautilus centralis* Sow., *N. imperialis* Sow., *Aturia ziczac* Bronn, *Belosepia sepioidea* Blv., *Voluta Wetherellii* Sow., *V. nodosa* Sow., *Aporrhais Sowerbii* Mant., *Cyrena cuneiformis*, *Cryptodon* (*Axinus*) *angulatum* Sow., *Leda amygdaloides* Sow., *Pinna affinis* Sow. Vertebrates: *Tetrapterus priscus* Ag., *Pristis bisulcatus* Ag., *Lamna elegans* Ag., *Palæophis toliapicus* Owen, *Crocodilus toliapicus* Cuv. & Owen. Tapir-like Mammals, *Lophiodon minimus* Owen, *Hyracotherium leporinum* Owen, *Coryphodon Eocænus* Owen; the Carnivore, *Palæocyon*.

Middle Eocene of England. — *Nummulites levigatus* Lam., *Cardita planicosta* Lam., *Pleurotoma attenuata* Sow., *Turritella multisulcata* Lam., *Conus deperditus* Brngt., *Lucina serrata* Sow.; *Myliobates Edwardsi* Dixon, *Carcharodon angustidens* Ag., *Otodus*

obliquus Ag., *Galeocerdo latidens* Ag., *Lamna elegans* Ag. (126 out of the 193 species occur also in the Calcaire Grossier in France.) Reptiles, *Palæophis typhæus* Owen, *Gavialis Dixoni* Owen, *Crocodilus Hastingsiæ* Owen; Mammals, *Dichodon cuspidatus* Owen, *Lophiodon minimus* Cuv., *Microchærus erinaceus* Wood, *Paloplotherium annectens* Owen.

UPPER EOCENE OF ENGLAND. — (1.) Barton Series. — *Mitra scabra* Sow., *Voluta ambigua* Lam., *Typhis pungens* Morr., *Voluta athleta* Sow., *Terebellum fusiforme* Lam., *T. sopita* Morr., *Cardita sulcata* Morr., *Crassatella sulcata* Sow., *Nummulites variolarius* Morr. (variety of *N. radiatus* Sow.), *Chama squamosa* Brand.

(2.) Headon Series. — *Planorbis euomphalus* Sow., *Helix labyrinthica* Say, *Neritina concava* Sow., *Limnæa caudata* Edw., *Cerithium concavum* Desh.; *Lepidosteus;* Reptiles, *Emys*, *Trionyx;* Mammals, *Palæotherium minus* Cuv., *Anoplotherium*, *Anthracotherium*, *Dichodon*, *Dichobune*, *Spalacodon*, *Hyænodon* (a dog-like Carnivore).

(3.) Bembridge Series (120 feet thick). — *Cyrena semistriata* Desh., *Paludina lenta* Desh., *P. orbicularis* Voltz., *Melania turritissima* Forbes, *Cerithium mutabile* Lam., *Cyrena pulchra* Morr., *Bulimus ellipticus* Sow., *Helix occlusa* Edw., *Planorbis discus* Edw.; *Trionyx; Palæotherium magnum* Cuv., *P. medium* Cuv., *P. minus* Cuv., *P. minimum* Cuv., *P. curtum* Cuv., *P. crassum* Cuv., *Anoplotherium commune* Cuv., *A. secundarium* Cuv., *Dichobune cervinum* Owen, *Chæropotamus Cuvieri* Owen.

LOWER MIOCENE OF ENGLAND. — Hempstead beds. — *Corbula pisum* Sow., *Cyrena semistriata* Desh., *Cerithium plicatum* Lam., *C. elegans* Desh., *Rissoa Chastelii* Nyst, *Paludina lenta*, *Melania fasciata* Sow., *M. costata* Sow.; the Mammal, *Hyopotamus bovinus* Owen.

PLIOCENE OF ENGLAND. — In the Coralline Crag, *Terebratula grandis* Blumb., *Lingula Dumortieri* Nyst, *Astarte Omalii* Lajonkair, *Cardita senilis* Gein., *Cyprina rustica* Flem., *Ostrea princeps* Wood, *Pecten Gerardi* Nyst, *Pyrula reticulata* Lam., *Bullæa bicatenata*, *Voluta Lamberti* Sow., *Echinus Woodwardii* Desor, *Temnechinus excavatus* Forbes. In the Red Crag, *Terebratula grandis*, *Astarte obliquata* Sow., *A. Omalii*, *Cardium angustatum* Sow., *Ostrea princeps*, *Pectunculus variabilis* Sow., *Nucula Cobboldiæ* Sow., *Columbella sulcata* Wood, *Cancellaria costellifera* Wood, *Cypræa Europæa* Mg., *Fusus antiquus* Lam. (*Trophon antiquum* Wood), *Nassa reticosa* Wood, *Purpura tetragona* Sow., *Scalaria Grænlandica* Beck., *Voluta Lamberti* Sow., *Felis pardoides* Owen, *Mastodon Arvernensis* Croizet & Jobert (*angustidens* Owen), *Rhinoceros Schleiermacheri* Kaup (*incisivus* Cuv.), *Tapirus priscus* Kaup (*Arvernensis* Croizet & Jobert), *Cervus anoceros* Kaup. In the Norwich Crag, *Rhynchonella psittacea* Turton, *Nucula Cobboldiæ*, *Panopæa Norvegica* Sow., *Tellina obliqua* Sow., *Astarte borealis* Nilss., *Cardium edule* Linn., *Cyprina Islandica*, *Pholas crispata* Linn. (*lata* Lister), *Fusus antiquus*, *Litorina litorea* Linn., *Natica helicoides* Johnston, *Turritella communis* Risso, *Scalaria Grænlandica*, *Mastodon Arvernensis*, *Elephas meridionalis* Nesti, *Cervus.*

LOWER EOCENE OF FRANCE. — *Argile plastique*, many species identical with those of the London Clay. The Bird, *Gastornis Parisiensis.* The "Sables de Bracheux," supposed to be of the age of the Thanet Sands, have afforded the Carnivore *Arctocyon primævus* Mey. (between *Cercoleptes* and the Bear).

The Upper Eocene of France has afforded nearly sixty species of Mammals, of the genera *Palæotherium*, *Anoplotherium*, *Xiphodon* (*X. gracilis*); the Carnivores, *Hyænodon* (*H. leptorhynchus* Blv.), *Canis Parisiensis* Cuv., *Cynodon Parisiensis* Pomel, besides Bats and an Opossum.

The Auvergne beds, between the Eocene and Miocene in age, contain more Carnivores in proportion, besides more modern genera. Among them, there are *Machærodus*, *Hyænodon*, *Cynodon*, *Canis*, *Amphicyon*, *Viverra*, of the Carnivores; *Palæotherium*, *Tapirus*, *Anthracotherium*, *Hyopotamus*, *Rhinoceros*, of Pachyderms; *Erinaceus*, of Insectivores; *Archæomys*, *Mus*, *Castor*, *Steneofiber*, *Lepus*, of Rodents, etc.

Some of the Miocene genera are *Pliopithecus*, *Dryopithecus*, of Quadrumanes; *Machærodus*, *Felis*, *Hyænarctos*, *Hyæna*, *Canis*, *Viverra*, *Mustela*, of Carnivores; *Mastodon* (*M. longirostris*, *M. tapiroides* Cuv., etc.), *Elephas*, *Rhinoceros*, *Listriodon*, *Sus*, *Anchitherium*, *Hipparion*, *Equus*, *Hippopotamus*, of Pachyderms; *Camelopardalis*, *Anti-*

lope, *Cervus*, of Ruminants; *Dinotherium*; *Erinaceus*, *Talpa*, of Insectivores; *Halitherium*, *Squalodon*, *Physeter*, *Delphinus*, of Mutilates.

A few of the Pliocene genera, in addition to the modern ones already enumerated, are *Pithecus*, *Semnopithecus*, of Quadrumanes; *Machærodus*, *Ursus*, *Phoca*, of Carnivores; *Lepus*, *Putorius*, *Arctomys*, *Lagomys*, *Arvicola*, *Castor*, of Rodents; *Balæna*, *Balænodon*, of Mutilates.

The Tertiary Mammals of the Sivalik Hills, India, from beds supposed to be Upper Miocene, include, besides *Quadrumana*, species of *Hyænarctos*, *Hyæna*, *Machærodus*, *Felis*; *Elephas*, *Mastodon*, *Rhinoceros*, *Hexaprotodon*, *Hippotherium*, *Equus*, *Hippopotamus*, *Sus*, *Anoplotherium*, *Chalicotherium*, *Merycopotamus*, *Camelus*, *Camelopardalis*; *Sivatherium*, *Antilope*, *Moschus*, *Ovis*, *Bos*; *Dinotherium*; *Hystrix*; *Enhydriodon*. The *Sivatherium* was an elephantine Stag, having four horns, allied to the Deer, but larger, being in some points between the Stags and Pachyderms. It is supposed to have had the bulk of an elephant, and greater height. *Bos* and the related genera probably occur nowhere earlier than the Pliocene. There were *Crocodiles* of large size, and the great turtle *Colossochelys Atlas*.

Noted localities of fossil fishes are Monte Bolca, near Verona, in northern Italy, of the age of the Nummulitic beds or Middle Eocene; Canton of Glaris, in Switzerland, in hard black slate, probably of the same era; Aix in Provence, and also in Auvergne, of the Upper Eocene or Lower Miocene; at Turin, Touraine, Vienna, Germany, etc., of the Miocene; Œningen, of the Pliocene; also at Mount Lebanon in Asia Minor, of the early Tertiary.

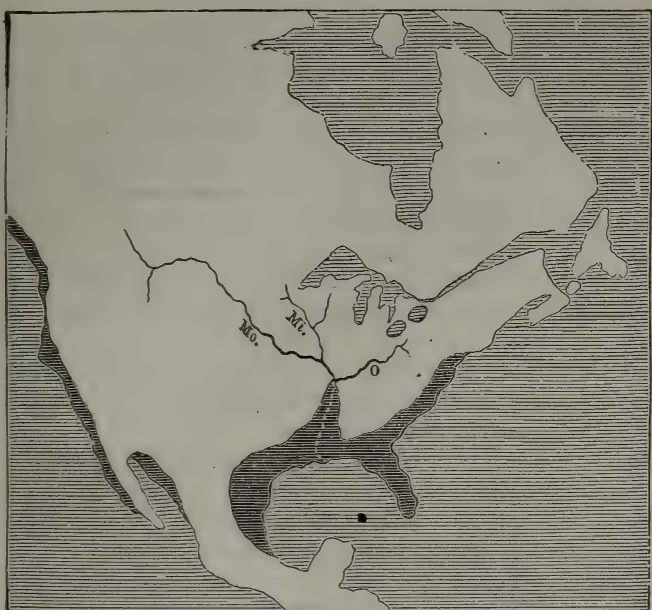
3. General Observations.

1. American Geography. — From the region of the Mississippi westward to the Pacific, the great continental seas, in which the *Cretaceous formation* was in progress, were for the most part shallow oceanic areas; and they covered nearly this whole range of country, excepting the sites of the Archæan mountains, that of the great plateau between the meridians of the Wahsatch and Sierra Nevada, and some other areas of Jurassic, Triassic, or older rocks. In the Rocky Mountain region, and also in California, the country from north to south was undergoing during the Cretaceous period a gradual subsidence, as already explained (p. 487); and thus the thousands of feet of rock were slowly accumulated in waters that were never deep. As the era drew toward its close, the subsidence appears to have intermitted for long intervals, with perhaps some upward movements, so that the land became slightly emerged. Later, the eras of intermitted subsidence became greatly prolonged, so that immense peat beds were formed from the vegetation growing over the quiet marshes; but, between, in the intervening eras, during which the sinking was renewed, thick sand-beds and clay-beds were made, containing marine or fresh-water shells, or both commingled, — these intervening between the coal beds, and the whole making up the Tertiary deposits of the Lignitic era.

Thus gradually, so far as rock-making was concerned, the Cretaceous era ended, and the Tertiary age began.

The same kind of change, from constant submergence to an era of occasional emergences, occurred over the eastern Rocky Mountain slopes, even into the Mississippi valley; and also in California on the west; for the Lignitic beds of Mississippi and Tennessee, and those of California, show that the marine era of the Cretaceous was there followed by one of fresh-water or terrestrial depositions, in which leaf-bearing and lignite-bearing beds were formed. Further, the rocks which next follow the Lignitic beds — those of the Claiborne and Vicksburg series — give evidence that, after the Lignitic era, the subsidence was again renewed; for the deposits are again marine in the Mississippi valley and about the Mexican gulf; and, although fresh-water over the Rocky Mountains, they have there a thickness of several thousands of feet, as evidence of the subsidence in progress.

Fig. 929.



North America in the Period of the Middle Tertiary.

The epoch of cold, which terminated the life of the Cretaceous Continental seas, would not necessarily have been attended by breaks in the series of rocks; and no such breaks are found in the Rocky Mountain region. The cold winds and oceanic currents appear to have done thoroughly the work of extermination over Europe and eastern North America, but less completely in the seas bordering the Pacific; and

hence it is that traces of the Cretaceous fauna are found in the Tertiary beds, even through the whole of the Lignitic Eocene.

With the opening of the second period of the North American Tertiary, the Alabama period, the continent had nearly the form represented on the accompanying map, as shown by the distribution of the areas covered by *marine beds.* The Atlantic Border was submerged, nearly as in the Cretaceous period: there was no Delaware or Chesapeake Bay, and no Peninsula of Florida. The Mexican Gulf spread far beyond its present limits north and west, but not, as in the preceding era, over the Rocky Mountain slopes. The Ohio and Mississippi were barely united at their mouths, if not wholly disjoined. Owing to the elevation of the land westward, the Missouri and other streams rising in the mountains had begun to exist. Yet this elevation was small; and, as Hayden has rightly inferred from the great fresh-water Tertiary deposits, the country was mostly covered by vast fresh-water lakes.

After the close of the Vicksburg epoch, referred to the Upper Eocene, there appears to have been a further reduction of the Mexican Gulf; for no later marine Tertiary beds are recognized on its borders. The "Grand Gulf beds," described by Hilgard as covering a coast region, south of Vicksburg, appear, as he observes, to indicate that, for a period after the Eocene and before the Quaternary, the coast line was along their northern border; but no marine fossils occur in them, and the particular period to which the beds belong is uncertain.

The Atlantic Tertiary region must have remained submerged until after the Miocene era. The absence, from most parts of the coast, of deposits that can properly be identified as Pliocene is a remarkable fact, and seems to show that the continent, during the Pliocene era, had at least its present breadth along the larger part of the Atlantic coast, if not a still greater eastward extension.

The change of water-level, which caused this enlargement of the area of dry land, was probably not confined to the border of the continent, but was part of a general change, in which a large part of the continent partook, especially the Rocky Mountain region.

2. European Geography. — In the earliest epoch of the Tertiary, in Europe, there appears to have been, as has been observed by others, first, an emergence of the land from the Cretaceous seas, when the Chalk formation was eroded at surface, and a flint conglomerate in some places formed; and when, moreover, in some parts, Lignitic beds were made, as in America. The return of the land to the sea-level, and in some places to beneath it, commenced the formations of the marine and estuary Tertiary of the succeeding epoch; and a still more general submergence brought about the state when the great Nummu-

litic beds of the Middle Eocene were forming over so large a part of Europe, Africa, and Asia, even over regions which are now occupied by the lofty mountains of these continents. At this epoch, Europe was again an archipelago, as in the Cretaceous period. The Paris basin was one of its great estuaries, varying between fresh and marine waters, with changes of level and changing barriers.

After the Eocene, in Europe (as well as in America), the marine deposits had much smaller extent; and the continent was mostly dry land. But the ocean-border, instead of having the American simplicity, had numerous deep indentations and winding estuaries.

But the geographical conditions here described were brought about, in connection with mountain-making on a vast scale, at different epochs in the course of the Tertiary.

3. Disturbances during the progress of the Tertiary Age. — In the Tertiary age, nearly all the great mountain chains of the world either were made or received additions of many thousands of feet to their heights, and hundreds of thousands of square miles to their areas; and, besides, far the larger part of igneous eruptions then took place.

(1.) The *first epoch of disturbance in North America* was one closing the Lignitic era. As has been stated, the Lignitic group in the Rocky Mountain region is upturned at all angles, to verticality, beneath the fresh-water Tertiary of the Middle and Later Eocene. Its deposition followed on after that of the 10,000 feet of Cretaceous strata without interruption, and added several thousands of feet to the conformable beds, the whole indicating the progress of a geosynclinal of remarkable depth. So, again, in California, some hundreds of feet were added, above the Cretaceous series. Apparently simultaneously, in these two regions, 500 miles apart, one west of the Sierra Nevada, and the other east of the Wahsatch, an upturning began which made mountains now 3,000 to 4,000 feet high in California, consisting mainly of Cretaceous rocks, and also elevations of considerable extent in the Rocky Mountain region.

(2.) The *second epoch of disturbance* was that closing the Alabama period, or the Eocene era. At this time, the borders of the Mexican Gulf, which had been under the sea, emerged, so that the later Tertiary beds — the Miocene — are confined to the Atlantic Border. The Rocky Mountain region, in Wyoming, Utah, and Colorado, may have also been lifted to some small extent.

(3.) The *third epoch of disturbance* closed the Miocene era. At this time, the Tertiary of California, which had accumulated to a thickness of 4,000 or 5,000 feet, over the tilted Lignitic beds and Cretaceous strata, and in a more westerly trough or geosynclinal than the

geosynclinal of the Cretaceous, was upturned and made into mountain ridges along the Coast region, parallel with the Cretaceous ridges and Sierra Nevada. Again, over the eastern slope of the Rocky Mountains, there was, at the close of the Miocene, a great contraction of the lake region; for the Pliocene lacustrine beds have, according to Hayden, a much more limited distribution. This is evidence that the elevation of the Rocky Mountains had gone forward during the period. There is proof that mountain-making pressure, from the Pacific direction, had acted with energy against the continental crust, in the occurrence of extensive areas of igneous rocks over the Pacific slope and part of the summit region. The vast areas of trachyte and doleryte show that immense regions were flooded by outpourings from fractures, at successive times. These eruptions continued to take place over those regions, at intervals, from the close of the Miocene even into the Quaternary age; and they have not even now altogether ceased; so that it is not easy to decide the particular date of the successive outflows. The beds form ramparts of basaltic columns, in several ranges, along the Snake River, or upper Columbia, and have a thickness there of 700 to 1,000 feet (King); in the cut through the Cascade range the thickness is over 4,000 feet (LeConte). As these eruptions far exceed all those of earlier time, they may be looked upon as the results of mountain-making pressure, after the crust had become so stiff, from its successive thickenings and the consolidations of the superficial deposits, that it could not bend, and hence broke. The rocks of the eruptions after the close of the Miocene, included both trachytic and dolerytic kinds.

On the Atlantic Border, the elevation of the coast, which placed the Miocene beds above the sea-level, may have taken place at this time, as above remarked. There is probable proof of elevation contemporaneously with the Rocky Mountain movements of this era, in the present height of the Tertiary in parts of Georgia and Alabama; for, while in general the beds on the Gulf Border are but one hundred to two hundred feet above the sea, near Milledgeville, Georgia, they are now six hundred feet, and near Montgomery about eight hundred feet. The position of the region, in a line with the general trend of Florida, suggests that its elevation may have been connected with that of the Peninsula of Florida itself. Moreover, the *northwestward* trend corresponds with that of the Rocky Mountain region, and not with that of the Alleghany range, which was raised soon after the Paleozoic. In San Domingo, according to Gabb, the Miocene has an elevation of two hundred to two thousand feet.

The elevation of the Rocky Mountains, which took place in the course of the Tertiary, and which had reached fully its present limit by the close of the age, amounted to not less than eleven thousand

feet: for marine deposits of the Cretaceous era exist in the mountains at this elevation.

Thus the North American Continent, which, since early time, had been gradually expanding in each direction from the northern Azoic, eastward, westward, and southward, and which, after the Paleozoic, was finished in its rocky foundation, excepting on the borders of the Atlantic and Pacific and the area of the Rocky Mountains, had reached its full expansion at the close of the Tertiary period; and even these border regions received afterward but small additions. The progress from the first was uniform and systematic: the land was at all times simple in outline; and its enlargement took place with almost the regularity of an exogenous plant.

In Europe, the elevation of the Pyrenees took place after the Middle Eocene, or at the close of the formation of the Nummulitic beds; and the same was true of the Julian Alps, and of the Apennines, Carpathians, and also other heights in eastern Europe. The Nummulitic strata have now a height of ten thousand feet in the Alps, and nine thousand in the Pyrenees. The elevation of the chain of Corsica, and some minor disturbances, in Italy and other parts of Europe, are referred to the close of the Eocene. The western Alps, ranging N. 26° E., which include Mount Blanc, Mount Rosa, etc., were raised, according to Elie de Beaumont, after the deposition of part or all of the Miocene; for the Molasse of this region was raised or disturbed by the uplift, and not the Pliocene. In Britain, there were great eruptions of igneous rocks during or at the close of the Miocene, according to Geikie, the dolerytic rocks, from the south of Antrim through the chain of the Inner Hebrides to the Faroe Islands, being part of the results. The igneous beds of the Hebrides are three thousand to four thousand feet in thickness, and overlie beds containing leaves of Miocene plants. The Antrim deposits cover eight hundred to twelve hundred square miles, and have an average thickness of five hundred and forty-five feet. The earlier volcanic eruptions of Auvergne and Velay are referred to the same era. The larger part of the dolerytic and trachytic eruptions of Europe are of Tertiary origin.

The elevation of the eastern Alps, from Valais to St. Gothard, along the Bernese Alps, and eastward to Austria, ranging N. 74° E., is attributed by the same geologist to the close of the Pliocene, as it lifted the Pliocene, but did not disturb the Quaternary. Even in the later part of the Pliocene era, there was an elevation of three thousand feet, in a part of the island of Sicily (p. 512). Thus, throughout the Tertiary period, the continents of Europe and Asia, as well as America, were making progress in their bolder surface features, as well as in the extent of dry land; and the evidence is sufficient to show that,

when the period ended, the continents had their mountains raised in general to their full height.

4. Climate. — The climate of the United States, even the Northern, during the Early Tertiary, was at least warm-temperate, as indicated by the fossil plants.

There is evidence, as Dr. Gray has remarked,[1] from the distribution of Tertiary plants in the Arctic, made known by Heer and others, and their relation to similar kinds in the Eastern United States and in Asia, that the northern parts of the Continents of America, Asia, and Europe were, during that age, under a nearly common forest vegetation, with a comparatively moderate climate. The genus *Sequoia*, of California, has its species (as Heer has shown) in the Miocene of Greenland, Arctic America, Iceland, Spitzbergen, Northern Europe; and one Greenland species is very near the great Californian *S. gigantea*; and these were successors to Arctic Cretaceous species. There were two species of *Libocedrus* in the Spitzbergen Miocene (Heer); and one (*L. decurrens* Heer) now lives with the Redwoods of California, while the other occurs in the Andes of Chili. Gray adds that the common *Taxodium*, or Cypress, of the Southern States, occurs fossil in the Miocene of Spitzbergen, Greenland, and Alaska, as well as Europe, and also, according to Lesquereux, in the Rocky Mountain Miocene. These are only a few of the facts. From the Miocene plants of Greenland (p. 514), Heer concludes that the mean annual temperature of the Arctic regions, in the Middle Tertiary, was as high as 48° F.

Europe evidently passed through a series of changes in its climate, from tropical to temperate. According to Von Ettingshausen, the Eocene flora of the Tyrol indicates a temperature between 74° and 81° F.; and the species are largely Australian in character. The numerous palms in England, at the same period, indicate a climate but little cooler.

The Miocene flora of the vicinity of Vienna, the same author pronounces to be *subtropical*, or to correspond to a temperature between 68° and 79° F.: it most resembles that of subtropical America. Farther north in Europe, the flora indicates the *warm-temperate* climate characterizing the North American Tertiary; and it is also prominently North American in its types. In the Pliocene, the climate was cooler still, and approximated to that of the existing world.

The North American feature of the Miocene forests of Europe was probably owing to migration *from America* through the Arctic regions, and not from Europe; for a number of the European species, as shown by Lesquereux (p. 498), existed already in the American Eocene. The

[1] *Mem. Am. Acad.*, vi. 1859, and *Am. Jour. Sci.*, III. iv. 292.

Australian feature also may have been a result of migration, but from the opposite direction. The Indian Ocean currents favor migration northward, along the borders of Asia, and not that in the opposite direction.

II. THE QUATERNARY AGE, AND ERA OF MAN.

Hitherto, through the ages, to the close of the Tertiary period, the continent of North America had been receiving a gradual extension to the southward, spreading itself southeastward on the Atlantic side, and southwestward on the Pacific. The scene of prominent action here changes; and, in the Quaternary, the great phenomena are mainly *northern*. The same general fact is true for all the continents, north and south: the changes affect most decidedly the *higher latitudes* of the globe. The Quaternary in America includes three periods: —

1. The GLACIAL, or that of the Drift; 2, the CHAMPLAIN, and 3, the RECENT or TERRACE.

1. GLACIAL PERIOD.

1. AMERICAN.

I. Material, Phenomena, and Distribution of the Drift.

1. *Drift.* — The term *Drift*, as it is commonly employed in Geology, includes the gravel, sand, clay, and bowlders, occurring *unstratified*, or without order of arrangement, over some parts of the continents, which have been transported from places commonly in higher latitudes, by some agency which (1) could carry masses of rock hundreds of tons in weight, and which (2) was not always dependent for motion on the slopes of the surface.

Other portions of the same transported material are stratified sands, clays, pebble beds, and cobble-stone beds; and these are *stratified* Drift. The latter is sometimes called *modified* Drift; but the material was often stratified in its first deposition, making the term *modified* inapplicable. The lower part of the unstratified Drift, is often a bed of clay, containing stones or *bowlders*, called the *bowlder clay*.

The unstratified and also the stratified Drift, over the interior of the continent, contain *no marine* fossils; while drifted logs and other accumulations of vegetable material, and, in the stratified, fresh-water or land shells, are not uncommon. Toward or along the sea-shores, the stratified beds often contain marine shells.

Nearly all the stratified Drift, and a large part of the unstratified, were deposited during the Champlain period; and hence the description of the former is given with the account of that period.

2. *General Geographical Distribution of the Drift.* — The unstratified Drift in North America occurs from Canada and Labrador northward, and west to a northwesterly line passing not far west of Lake Winnipeg; over New England and the islands south; New York, New Jersey, and part of Pennsylvania; the States west, including Iowa and Minnesota, to the meridian of 98° W., and not beyond.

It has its southern limit near the parallel of 39°, in southern Pennsylvania, Ohio, Indiana, Illinois, and Kansas; but its northern is undetermined. South of the Ohio River, it is hardly traceable; yet it is stated to occur near Ashland, in Boyd County, Kentucky. Few bowlders are found about Baltimore and Philadelphia, and these not on the higher lands. It is thus northern in its distribution. Still, ***local*** Drift deposits have been recognized, descending from the Unaka Mountains (the range between Tennessee and North Carolina), along tributaries of the Tennessee River, and in the Alleghany Mountains, West Virginia; and of far greater extent about the crest ranges of the Rocky Mountains, the Sierra Nevada, down to latitude 35° N., the peaks of the Cascade Mountains, and other high ranges on the Pacific Border.

In East Tennessee, the stones of the Drift are of all sizes, to a diameter of eight or ten inches, and the trains have a height of 300 to 400 feet above the streams, in their upper portions, according to Safford, and of 170 feet at Knoxville, according to F. H. Bradley. R. P. Stevens has announced the occurrence of similar "bowlder Drift," in Greenbrier valley, West Virginia, on the west slope of the Alleghanies, and also near Covington, Va., along the head waters of the James, on the opposite or east side. The trains are valley trains, not continental and northern, like the true Drift. In the Rocky Mountains, and in Nevada, California, and Oregon, there is no *northern* Drift, according to Whitney; but there are unstratified and stratified Drift deposits of great thickness, following the course of the valleys from the higher mountains. Belt states that there are bowlder-clays in Nicaragua, 2,000 to 3,000 feet above the sea.

The closing Tertiary age must have left the continent covered with alluvial and lacustrine deposits, and among them beds of peat, and shell-beds of fresh-water origin. The preceding pages contain an account of such deposits over the Rocky Mountain slopes. But little is known of any such beds, north of the Drift limit, east of the Mississippi: they appear to have been mostly rearranged, in the making of the Drift. The whole country must have been a vast forest region. The forests were all swept off; for existing forests over the hills are planted in general upon the Drift deposits, or on material of later formation.

Distribution in Elevation. — The unstratified Drift extends not only over the lower country, but also high up the mountains; to a level of 5,800 feet on the north side of Mt. Washington, and 4,400 feet on Mt. Mansfield, the highest peak of the Green Mountains. Bowlders, often of large size, occur on most of the New England summits under 4,000 feet in height.

3. *Material of the Drift.* — The unstratified Drift consists of (1) unstratified clay-beds, often with intermingled stones; (2) the bowlder-clay, already mentioned; (3) sand, or (4) gravel, in great deposits; (5) bowlders, small or large, distributed in or over the other deposits, — these bowlders sometimes fifty feet across, and weighing over 1,000 tons. About 11 cubic feet of trap make a ton, and 12 to 13 of other rocks.

The material, though varying much in different regions, is in general coarsest to the north, and becomes gravel and sand, without stones, or only small ones, toward the southern limit of the Drift region. Nearing this limit, it stretches farther south in the north-and-south valleys than on the hills.

The stones or bowlders sometimes lie in long trains, as in Richmond, Berkshire County, Mass., and Huntington, Vt., crossing hills and valleys, without following the line of slope; or going obliquely across a valley; or the stones of one ridge are found on another ridge separated from it by a deep valley.

One bowlder in Bradford, Mass., is 30 feet each way (Hitchcock), and weighs not less than 1,250 tons. Another, in Whitingham, Vt., in the Green Mountains, is 43 feet long and 32 in average width, and full 40,000 cubic feet in bulk. It lies on the top of a naked ledge. Many on Cape Cod are 20 feet in diameter, and one at Winchester, N. H., is 29 feet across.

4. *Source of the Material and Course of Travel.* — By comparing the Drift with the rocks of the country, it has been found that the course of travel was mostly from the north, — from the northeast, the north, or the northwest. To the eastward it was mainly *from the northwest;* but in western New York and Canada, and north of Lake Superior to and beyond Lake Winnipeg, generally *from the northeast.* The distance transported varies from a mile or less to more than one hundred.

From southwestern Vermont, the granite of a high hill, between Stamford and Pownal, which is almost as high as the Green and Hoosac Mountains lying to the east and southeast, has been carried southeastwardly across the western sides of these mountains, nearly across the State of Massachusetts.

Large bowlders strew thickly the north shores of eastern Long Island, which are the crystalline rocks, trap, and sandstone of New England; and others, on western Long Island, are from the Palisades and heights along the Hudson River. South of Lake Superior, there are bowlders which have come from the north shore of the lake.

The iron-ore bed of Cumberland, Rhode Island, furnished bowlders for the country south of Providence, thirty-five miles distant, while none are found to the northward.

South of the Lake Superior region (where native copper occurs) masses of this metal are found in the Drift, over Michigan, Ohio, Indiana, Illinois, Wisconsin, and Iowa: and bowlders full of fossils, derived from various Paleozoic rocks of the upper Mississippi, in the Drift of the States to the south, even down to Mississippi. The stones of the Mississippi Drift have been traced in part to Tennessee. Masses of native copper occur also in the Drift of Connecticut and New Jersey, that were taken from veins nearly north of the places where they occur. Native gold, from the rocks north of Lake Superior, occurs in the Drift of Ohio, Indiana, and the States west.

The *Transportation was sometimes across, and sometimes in accordance with, the slopes of the surface.*—The facts stated above, respecting lines of stones crossing valleys and hills without deviation from a right line, are examples of a very general fact with regard to the Drift. At the same time, the trains often follow the directions of the grander slopes of the surface, and especially the courses of the larger valleys.

On the other hand, bowlders were sometimes carried up slopes, to a height of a thousand feet or more. Thus, limestone bowlders from Canaan, Conn., were carried southeastward, up to Goshen, 1,000 feet: and fossiliferous bowlders from the region north of Mt. Katahdin were left on that mountain, at a height of 4,385 feet above the sea, or more than 3,000 feet above the low country to the north.

II. Attendant Phenomena — Groovings or Scratches.

1. *Evidences of Abrasion.* — Besides the transportation of stones and earth, there was the abrasion of rocks, which left nearly the whole rocky surface of the country, within Drift regions, scratched or grooved and polished. Figure 940 represents a slab of limestone thus scratched and planed off. In addition, the stones and large bowlders

Fig. 940.

Drift groovings, or scratches, from Western New York.

of the Drift are often scored, like the rocks they abraded. The bottoms of valleys are commonly scratched, showing that the deposition of most of the stratified, as well as unstratified Drift, took place *after the era of greatest abrasion.*

The bare ledges have not often retained the scratches, unless they consisted of slate, compact limestone, or a hard kind of gneiss. But these, and even softer rocks, are generally found to be grooved wherever the soil has been recently removed.

The groovings are long, straight, parallel lines, often like the lines of a music-score, or broad planings, ploughings, and gougings of the surface. The scratches generally

vary from fine lines to furrows three or four inches deep; but they are occasionally a foot deep and several feet wide; or even two feet deep, as on the top of Monadnock (Hitchcock); and even eight to ten feet deep, making great mouldings of the surface, as in the Connecticut River sandstone, in North Haven (near New Haven, Ct.); and four to six feet in compact limestone, near Ithaca, N. Y. At the same time, the variations, from broad smooth planings and ploughings to deep groovings and fine scratches, show variations in the moving mass. The channels are sometimes made of broken lines, or successions of slight curves, as if from hitches in the progress of the gouging agent; and the edge of a layer, where there was a sudden descent, is occasionally chipped off, as if the heavy body had gone down with a jump.

Rocky ledges have been left with polished and rounded surfaces, like those called, from their shape, in the glacier regions of the Alps, *roches moutonnées* (or *sheep-backs*) (p. 699).

Again, the scratches exist over the higher summits of the country, as well as over the lower, — occurring on Mount Mansfield, in the Green Mountains of Vermont, 4,400 feet above the sea level, and on the White Mountains to a height of 5,500 feet. Moreover, the north side of a ridge or summit has often been smoothed off and made steep, when the southern has been left with a gradual slope. The north side, in such cases, is called in Sweden the *stoss* or *struck* side.

2. *Direction of the Scratches.* — The direction of the scratches corresponds with that of the movement of the Drift, being in general southward, or southeastward in New England, but southwestward in Western New York, near Lake Huron, Lake Superior, and Lake Winnipeg.

On the higher summits of northern New England, the average course is approximately S. 40° E.; to the eastward, in Maine and adjoining parts of Canada, S. 50° to S. 66° E., increasing in easting to the eastward; in western Connecticut and New York adjoining, about S. 25° E.; in western New York and on the eastern side of Lake Huron, S. 35° W.; on the northeast side of Lake Huron, S. 37°–45° W.

Over the lower lands of a country, there is commonly some conformity to the general slopes of the surface, or to those of the principal river valleys, as stated with regard to the Drift itself. While the scratches follow the course of the Connecticut valley, in the valley itself (averaging S. to S. 15° E., for 100 miles north of Massachusetts; S., in Massachusetts; S. 10°–25° W., in Connecticut), to the east, as well as west, of the valley, over the higher land, the same southeasterly course prevails that is usual over the more elevated parts of New England. (Am. Jour. Sci., III. ii. 233.) Along the valleys of the Lamoille, the Winooski, and Otter Creek, in Vermont, of the Merrimack in Massachusetts, and in the lower part of the Lake Champlain valley, the scratches have the directions nearly of the valleys. In western New York and western Canada, and about the eastern borders of Lake Huron, the prevailing course of the scratches is southwest; but, at many points south of the eastern arm of Lake Huron, called Georgian Bay, as recorded by Logan, it is southeast; and this is so, apparently, because this is the course of the Georgian Bay depression.

There are sometimes *two or more sets of groovings*, differing in direction. For example, in western New York, there is, in addition to the southwest system, a subordinate south system (Hall); and, on Isle La Motte, in Lake Champlain, there are eight sets (Adams), although usually not over two or three in Vermont.

Western and Southern North America. — In the Rocky Mountains, the Sierra Nevada, and other western ranges, there are scratches, polished rocks, and *roches moutonnées* of vast extent, as well as the local Drift alluded to on page 528; and, like the Drift, they have, in general, the courses of the valleys or slopes. On Vancouver's Island, near Victoria, however, the scratches have a south-southwest course (magnetic), and others a south-southeast; and these may be connected with a true northern Drift.

Scratches and polishing of rocks, of limited extent, have been observed by R. P. Stevens, either side of the Alleghanies, in West Virginia, accompanying the Drift described as occurring there, on page 528.

The scratched and polished rocks of the Sierra Nevada are of great extent and perfection about Mount Lyell and several other higher summits of the Sierra Nevada, as described by Whitney, King, and Le Conte. They are very remarkable also about the Crest range of the Rocky Mountains, in Colorado, as observed by Hayden & Gardner. A portion of one of the valleys leading away from the Mountain of the Holy Cross (covered with "sheep-backs") is represented in Fig. 1106, on page 685, from a sketch from Hayden's Report.

3. *Forced Migration of Plants.* — On the summits of the White Mountains, the Adirondacks, and some peaks of the Green Mountains, and other places, less elevated, there are species of subalpine plants, which are believed to have migrated southward in Glacial times.

Thirty-seven kinds, according to Dr. Asa Gray,[1] occur on the White Mountains alone, and part of them on the Adirondacks and Green Mountains. Besides these, *Sedum Rhodiola* D. C., a subalpine species, occurs on cliffs of the Delaware, below Easton, Pa.; *Saxifraga oppositifolia* Linn., on Mount Willoughby, in Vermont; *Arenaria Grönlandica* Sprengel, a Greenland species, is found on the top of the White Mountains, the Catskills, Shawangunk Mountain, and, in the form of *A. glabra* Michx., on the Alleghanies of Carolina; *Scirpus cæspitosus* Linn., alpine and subalpine, has a patch remaining on Roan Mountain, North Carolina; *Nephroma Arcticum* Fries, and other northern Lichens, with *Lycopodium selago* Linn., still live on the highest Alleghanies.

2. Drift in Foreign Countries.

The Drift material presents the same characteristics on the other continents as in North America. It is confined to the *northern* half of Europe; that is, Britain, Denmark, Scandinavia, Russia, Poland, and northern Germany, down, in some portions, to the parallel of 51°, — a line which has nearly the same mean temperature now as the southern limit, 39°, in the eastern United States. In South America, it is met with, from Tierra del Fuego, as far toward the equator as 37° S., and especially, as Agassiz has shown, in the great valley between the main chain of the Andes and the Coast Mountains, where it was observed by him, to the latitude of Concepcion. It occurs likewise on the east side of the Andes; also over parts of New Zealand.

[1] *American Journal of Science*, II. xxiii., 62, 1857.

The course of the stones, gravel, and sand, and also that of the scratches, is, in the main, toward the equator.

In Europe, the Drift crossed the Baltic from Scandinavia southeastward over Western Russia, southward to Denmark, Germany, and Poland; and southwestward over the Faroe and Shetland Islands and to the coast of Norfolk, in England; and the distance of travel varied from five miles, or less, to five or six hundred. There is evidence also of transportation toward the Polar regions.

In Great Britain, the movements were mainly in the direction of the slopes of the mountains and their valleys, the Drift radiating from different centres, as the Highlands and Southern Uplands of Scotland, the mountains of the Lake country in northern England, and the Snowdonian heights in North Wales. There were local movements of Drift also about the Pyrenees, and from Auvergne down the Dordogne.

The Drift phenomena are exhibited on a grand scale about the Alps, especially along the valleys of the Rhone and Rhine. Lines of stones and gravel, and even great bowlders, have been traced (first by Professor Guyot) from the Alpine summits about Mount Blanc, by the valleys of the Trient and Rhone, to the plains of Switzerland, and thence over the sites of Geneva and Neufchatel to the Jura Mountains on the borders of France; and the declivity of this range, facing the Alps, is covered with the bowlders; one of them, the Pierre-a-bot, — a mass of granite (or more properly *protogine*), — is 62 feet long by 48 broad, and contains about 40,000 cubic feet, equivalent to a weight of 3,000 tons.

Moreover, the valleys of the Alps have their sides nearly horizontally grooved or planed, to a height of 10,000 feet above the sea, or more than two thousand feet above the present upper limit of the glaciers, or the level of any existing adequate abrading agency. The bowlders and scratches have been traced beyond Geneva, even to Lyons, and to Vienne, in Dauphiny.

About Mount Antilibanus, in Syria, in latitude 34° N., glacial phenomena have been observed; also on the southern side of the Himalayas, to within 4,000 feet of the sea level, if not to the plains of India; on the Atlas Mountains, in Northern Africa.

Forced Migrations. — Numerous examples have been observed, in Europe, of species of both plants and animals driven south by the conditions of the Glacial period. Subarctic shells are found in Quaternary deposits, on the borders of the Mediterranean; and one of the Glacial colonists, *Fusus contrarius* Kiener, still lives in Vigo Bay on the coast of Spain, with other Celtic species.

3. Fiord Valleys.

Another great fact that belongs to the Drift latitudes on all the continents, and may be connected in origin with the phenomena of the Glacial era, is the occurrence, on the coasts, of fiord valleys, — deep, narrow channels occupied by the sea, and extending inland, often for 50 or 100 miles. This geographical connection with the Drift is a striking one. Fiords occur on the northwest coast of Europe, from

the British Channel north, and abound on the coast of Norway. They are remarkably displayed on the coasts of Greenland, Labrador, Nova Scotia, and Maine. On the northwest coast of America, from the Straits of De Fuca north, they are as wonderful as along Norway. On the coast of South America, they occur in Drift latitudes, from 41° S. Drift latitudes are therefore nearly identical with fiord latitudes.

III. Origin of the Phenomena of the Glacial Period.

The Drift period is usually called the Glacial period, under the idea that ice, in the form of either icebergs or glaciers, was concerned in the transportation of the bowlders, pebbles, and earth. Ice may float masses of many thousand tons' weight, when in the condition of an iceberg; and so glaciers, as in the Alps, may bear along equally great masses of rock or earth. But simple running or moving water is incapable of such work. There are, then, two theories, the *Iceberg* and the *Glacier*. The former supposes large parts of the continents under the sea; the latter places the same regions above the sea, and perhaps at a higher elevation than now. They thus diverge at the outset.

1. *Iceberg Theory.* — (1.) The Iceberg theory supposes New England to have been submerged 5,000 feet or more below its present level. It requires, in fact, that the submerged area should have extended wherever the Drift occurs: and therefore this must have reached to the Ohio on the south, and beyond, according to some advocates of it, along the Mississippi valley to the Gulf of Mexico; and far to the north, over the British possessions, to a limit yet undetermined. But, in opposition to this hypothesis, there are, south of the latitude of Hudson's Bay, no shell-bearing sea-beaches, as evidence of such a submergence, beyond a height, at the most, of 500 feet.

It appeals, also, to the facts that —

(2.) The icebergs of the Atlantic are floated southward from the Arctic regions, and descend along the coast of Labrador and Newfoundland, and over the Newfoundland Banks, and, as they melt, cover the coast with bowlders and strew the sea-bottom with stones and earth.

(3.) The Labrador current (p. 40) has the direction of the Drift stones and scratches.

(4.) The material deposited by melting bergs would contain few, if any, sea relics.

(5.) Stones in the foot of a grounded berg would scratch the surface beneath.

(6.) The courses of the scratches in the St. Lawrence valley, not far from the river, and the Drift transportation were *up* stream, as if from the flow of the Labrador current, carrying ice, while the continent was submerged.

In the Iceberg theory, there are the following difficulties: —

(1.) There are no marine deposits or fossils of the era over the interior of the continent. The shore of the sea of the Drift period has not been traced by either beaches or shells. The greatest height of shore shell-beds in or near the United States is 470 feet; and this occurs on the St. Lawrence (p. 550); nothing of the kind occurs over the Ohio region, north or south of the river.

(2.) The icebergs of the Atlantic bring their burdens from the Arctic mountains, having gathered them while glaciers—for all icebergs are fragments broken from the lower ends of glaciers; while the stones and earth of the Drift were often carried less than fifty miles. Consequently, if icebergs were the means of transport in New England, those icebergs must have commenced as glaciers about New England mountains,—an idea which has its difficulty in the alleged fact (inferred from the scratches and stones) that even Mount Washington was all submerged but five hundred feet, and Mount Mansfield to its very top.

(3.) Scratches made by icebergs that chanced to be grounded could not score so uniformly, and so completely, the whole surface of a country; and could not have been made to conform so generally as they do, to the courses of the valleys.

(4.) Bowlders hundreds of tons in weight were taken up from the low hills in the Connecticut valley, and carried fifty miles, or less, to the south; and, if carried by icebergs, the berg must have picked up the great mass by its foot, which is not possible.

2. *Glacier Theory.*—This theory is sustained on the ground that—

(1.) Glaciers are known to transport bowlders, gravel, and earth; and they may carry the material short distances as well as long.

(2.) Glaciers make scratches in the rocks beneath them by means of the stones they carry at bottom, precisely like those of the Drift region as to regularity, kind, number, and all other peculiarities; and polished and rounded surfaces are other common effects from moving glaciers. Moreover, the stones themselves are scratched or polished.

(3.) Glaciers may make the scratches in large valleys in the direction of the valleys, when the main mass is moving in another direction. For, while they take their general course from the grander slopes of the upper surface of the ice-mass, the movement at the bottom will accord, more or less perfectly, with the slopes of the land-surface; just as thick pitch, descending a sloping plane having oblique furrows in its surface, would follow the general slope of the plane, but have an under part diverted by the furrows.

(4.) The presence of a considerable number of alpine or subalpine plants, within the limits of the eastern United States (p. 532), can be accounted for on the view of an era of glaciers, and not on that of icebergs.

(5.) The objection urged against the glacier theory, that the northern part of the continents does not afford a slope southward, to favor the movement, is of no weight, since no such slope was required. All that was needed was a general southward slope *in the upper surface of the glacier;* or simply a greater accumulation of ice to the north than to the south. The case is just like that of heaped-up pitch. If stiff pitch be gradually dropped over a horizontal surface it will spread, and continue so to do so long as the supply is kept up; and, if that surface rises at an angle in one direction, and there is no escape in any other, it will first fill the space to the level of the edge, and then drop over and continue onward its flow. So glaciers, if the accumulation is adequate, may go across valleys and over elevated

ridges. At the same time, as above stated, the *under* layers of the ice will follow, to some extent, the general slopes of the country passed over.

A glacier filling the St. Lawrence valley could not move down the valley (northeastward) if the ice were highest about its mouth; but it might, in such a case, move *up* the valley, or across New England; and, if the latter, the portion in the bottom of the valley would be likely to move up stream, because the valley, a groove in the land, might give direction to the bottom layer. Dr. Dawson has observed evidence that, in some parts of the St. Lawrence valley, the ice of the Glacial period did actually move up stream.

(6.) The glacial phenomena of the higher Rocky Mountain ranges, the Sierra Nevada, and other heights on the Pacific Border, and of the mountains of Virginia and North Carolina on the Atlantic, are all in harmony with the Glacier theory. The several regions, as recognized by all observers, are simply examples of glacier centres, like that of the Alps, where the mountains were lofty enough to determine the surface slope of the ice, in which case the glaciers of the region would necessarily have been *local* glaciers. They point to the Glacial period of the Continent as the time of their origin. A few traces of the old glaciers still linger about Mount Shasta, Mount Hood, and some other of the loftier summits; and two branches of the Saskatchewan head in glaciers, one of which is nine miles long and three wide.

Similarly, the glacial phenomena of Great Britain, the Alps, the Pyrenees, Mount Lebanon, and the Himalayas, are those of Alpine glacier centres, and cannot be explained without reference to the existence and action of glaciers. Geikie has shown that the great glacier from the Highlands of Scotland extended northwestward over the Hebrides, and southward and southwestward through the Irish Channel and over Ireland; and it probably reached northeastward to the Orkneys and Shetlands. The occurrence, in southern South America, of bowlders from the Cordilleras, scores of miles to the east of the mountains, as well as to the west on Chiloe, observed by Darwin, requires the same explanation.

The absence of glacier action, over a large part of the region from Virginia to Georgia and Alabama, is shown by the great depth of decomposed rock, covering *in situ* the crystalline rocks in many places; at the north, all such soft superficial material was scraped off and carried away by the glacier.

It hence appears that the glacier theory is alone capable, as first shown by Agassiz, of explaining all the facts.

The surface of the glacier in North America must have been of unblemished whiteness; for, from New England west to the Mississippi, there was not a peak above its surface, excepting the White Mountains, and these probably had their cap of snow. Hence among

the depositions, *lateral moraines* are not a characteristic feature, while *under-glacier* moraines, or linear ranges of stones and gravel are very common.

3. *Probable summit and limit of the ice of Eastern North America.* — The direction of the scratches, and the extent of the country they cover, appear to show (since they indicate the direction of movement, and therefore the slope of the surface of the ice) that, over New England and Eastern Canada, there was a gradual rise in the surface of the glacier toward the *northwest*, and over Western New York and Western Canada, toward the *northeast;* and that the ice-summit, or the region toward which the directions converge — and therefore the opposite slopes rise — was over the Canada Water-shed, nearly north of Montreal. From this its southern portion the broad ice-range stretched northward and northeastward; for this is proved by the *southwest* direction of the drift and scratches over the country from Lake Huron to and beyond Lake Winnipeg. Since evidences of the great southward moving glacier fail over the region west of a line passing from a few degrees west of Winnipeg, southeastward through Western Minnesota and Iowa, near the meridians of 98°–100°, and all the way westward to the borders of California and Oregon if not to the Pacific coast, the ice thinned out toward the interior of the Continent and was mostly absent except about the higher parts of the Rocky Mountains.

The glacier of the Northern Hemisphere was, therefore, not a great enveloping ice-cap extending far southward about the sphere. On the contrary, the polar ice had a broad and lofty southward prolongation toward the eastern border of the Continent; another narrow and shorter one on the western border; and also a southward extension, through local glaciers, along the higher portions of the Rocky Mountains.

The accumulation of ice, under a like degree of cold, depends on the amount of precipitation. Hence it is that the largest ice-range was on the Atlantic border; and, for the same reason, in connection with the high summer temperature, ice was mostly absent from the western interior, the annual amount of precipitation there being not over sixteen inches, which is less than half that of New England.

The height of the ice-surface at the White Mountains, as scratches and bowlders show, was at least 6,000 feet above the sea; and thence the surface rose toward the summit of the ice-range, and fell away toward the ocean which lay to the southeast, where was the place of discharge of the ice-stream. It is probable that the lofty ice-range of Eastern North America so intercepted the moisture from the ocean that Greenland and other Arctic lands had less precipitation than now, and perhaps less thickness of ice.

The conditions were similar in Europe. The Scandinavian mountain range, as made known by the Swedish Geologists, was the course of the great ice-mass, and hence, it

was the chief region of departure for the distribution eastward, southward, and westward, and to some extent northward, of the North-European drift.

The *lower limit* of the glacier off New England, may have been over the shallow border of the ocean, perhaps as far out as the fifty fathom or one hundred fathom line of soundings, which on the east passes outside of St. George's Shoal, and off Sable Shoal east of Nova Scotia. Long Island and the other islands off New England have been made by Clarence King and some other writers the course of a part of the terminal moraine; and a range of bowlder hills covering New Jersey, west of Perth Amboy, have been pointed out by Professor Smock as another portion of it. In Wisconsin the Green Bay Valley is bordered on the east, south, and west, by a range of stony hills, called the Kettle Range, and this range is described as of moraine origin by Chamberlin and Irving, and as directly connected with the Green Bay Valley ice during part of the era of ice. At the time of its greatest extension, the glacier reached to Southern Iowa and the border of Missouri, where occur bowlders and even native copper, derived from the Lake Superior region, and even into Kansas. A mass of copper found in Lucas Co., Iowa, travelled 460 miles, if it came from Keweenaw Point, the probable source.

The glacier produced part of its effects by becoming a dam in some places along the sides of the greater valleys, which set back the waters of the lateral channels, and made at times great lakes beneath the ice, and lacustrine depositions of clay, sand, or pebbles, at great elevations. (W. H. Niles.) As urged by Belt, the glacier may have formed along the Northern Coast of Asia an almost unbroken dam, preventing the outflow of the Great Siberian rivers; and the dam of ice may have continued, owing to the high latitude of the coast line, long after the ice had melted away farther south, and so have caused (in the Champlain Period) immense floods from the waters of the combined rivers, and thence the universal deposit of alluvium that characterizes the Siberian Steppes. (Milne.)

It is not generally possible to decide positively what Drift depositions were made in the Glacial period. Cases like the following, in which evidence exists of deposit during the *moving* of the glacier, probably belong to the period. West of New Haven, Conn., a rocky ridge, 300 to 400 feet high, has for several miles a rather bold front to the eastward, and thus stood obliquely to the glacier, which here moved S. 30°–40° W. Along it, near the top, there are multitudes of great bowlders, — one of them a thousand tons in weight, and many between fifty and five hundred tons, — which were evidently combed out of the passing ice by the projecting ledges.

4. *Erosion; gathering of material for Transportation.* — The Erosion of the glacier included (1) *abrasion*, performed through the stones

and earth in its under surface; and (2) a *tearing* and *scooping* action, dependent on the pushing action of the ice against weakly coherent beds, and against ledges of jointed or laminated rocks. With a weight of 450 pounds to the square inch for 1,000 feet of thickness, it pressed down into all depressions, filling the basins of lakes, the trough of Long Island, now 150 to 180 feet deep, and the crevices in the exposed rocks ; and, although the rate of motion could hardly have exceeded a foot a day, and may have been in most parts no more than a foot a week, it worked with great power, planing off and furrowing the harder rocks, excavating deeply the softer, and tearing masses from yielding ledges and rocky summits which lay beneath or projected into it. A broad abrupt hill sometimes saved from abrasion the soft deposits south of it, because of the great arched cavity or notch it made in the ice ; as, near New Haven, Conn., where a ridge of weak sandstone a mile long and 100 to 140 feet high was left under the lee of a trap ridge. The material worn off or loosened was taken into the glacier, and the lower 500 feet of the ice may have contained the most of it. As the glacier moved on, adjusting itself to its uneven bed, the ice-mass was throughout in motion, and the stones were consequently ground against one another, their edges rounded, and pebbles, sand, and earth for the bowlder clay, were made.

Moreover, since the snows of the commencing Glacial period fell over a continent of great forests, trees were everywhere rooted up or broken off with the first motion of the ice, and afterward partly ground up ; and finally, if not wasted by decomposition, deposited with the Drift, — some portions, perhaps, in beds of vegetable material, and others as scattered logs, stems, and roots. Land and fresh-water shells also would have been gathered up for transport and distribution.

The valleys of the continent owe their depth to erosion by the streams flowing in them. Much of the excavation was done in the Glacial period, partly by the direct action of the glacier, but vastly more by sub-glacial streams, laden with debris from the glacier. This excavation was carried much deeper in very many cases than could have been done with the continent at its present level. Dr. Newberry states that all the river valleys of Ohio are examples of this ; that the valley of Beaver River is excavated to a depth of 150 feet below the present river level; that of Tuscarawas River at Dover, 175 feet; that of the Ohio River, much deeper, 100 feet of boring near Cincinnati not reaching the bottom of the alluvium. Such facts are evidence of erosion at some period when the continent was *more elevated than now*, and are attributed by many to the agencies of the Glacial era. The remarks on fiords on pages 533 and 540 are in further illustration of this subject.

The *excavation of lake basins* also has been attributed to glacial action. In the case of many lakes in Alpine regions, the origin is due to the filling of the narrow outlet of a deeply excavated valley, by Drift. But, in some cases, especially when the rocks underneath the glacier were soft and easily abraded, the ice may have gouged deeply into the underlying deposits, and then have had this excavating action stopped by a barrier of harder rock in front; and thus a lake-basin may have resulted.

IV. Icebergs.

While the glacier theory affords the best and fullest explanation of the phenomena, over the general surface of the continents, and encounters the fewest difficulties, icebergs have aided beyond doubt in producing the results along the borders of the continents, across ocean-channels like the German Ocean and the Baltic, and, before the final disappearance (as explained in the account of the Champlain period), over the region of the Great Lakes of North America. Their effects are well exhibited along the coast of Labrador.

V. General Observations.

1. Geography — *The Glacial period a period of high-latitude elevation, and hence of deep valley-excavation.* — Elevations of land do not leave accessible records like subsidences. Still, there is evidence on this point deserving consideration.

(1.) The existence of an epoch of unusual cold in the early Quaternary, seems to be a natural sequence to the vast amount of elevation and mountain-making that had been going on in the Tertiary over all the continents (p. 525), and for the Rocky Mountain regions, late in the Pliocene Tertiary; for this upward movement must necessarily have resulted in increasingly cold climates over the earth.

(2.) The occurrence of fiords only in Glacial latitudes is further reason in favor of the supposed elevation; and of Europe as well as America. They are positive evidence that, in the era when they were made, the land stood above its present level, and high enough above to allow of their having been excavated, to their bottoms, by the flow along them of fresh water, or fresh water and ice — for they are *valleys of erosion;* moreover, the fiords on the coast of Maine increase in depth from the southwest to the northeast, showing that the amount of elevation increased in the same direction (Verrill). They may have been begun in earlier periods, and have been partly finished in the Cretaceous and Tertiary; but the almost precise identity of Glacial and fiord latitudes over the globe make it a reasonable supposition that the Glacial era did the finishing work, through the increased elevation of northern lands.

(3.) This argument from fiords is corroborated by the facts connected with the depth of river valleys, mentioned on the preceding page; and similar facts might be gathered from Europe.

Further, there is evidence, as shown by F. H. Bradley, that waters from Lake Michigan, in some era, cut a channel from the south end of the lake southwestward to the Mississippi, following a course south to the north line of Iroquois County, Illinois, and thence southwest through Champaign and McLean counties, — the western margin of the trough being well marked by buried escarpments, in some places two hundred feet or more in height. Lake Erie, in like manner, has been found, by G. K. Gilbert, to have discharged southwestward along the course of the Maumee, and not by overflow merely, but by a strong current which cut its trough. The under-sea course of the Hudson River channel has been pointed out on page 423; and there is a similar one, though less perfect, for the Connecticut outside of Long Island Sound. Again, General G. K. Warren has shown that Lake Winnipeg once discharged southward, through the Minnesota River Channel, into the Mississippi, instead of into Hudson Bay as now. Such facts are explained by him on the ground of a former elevation of the continent to the north. With an elevation of but two hundred feet along Southern New England, Long Island Sound would have been for the most part a fresh-water channel, tributary to the prolonged Connecticut.

(4.) The Atlantic coast of North America, to the north of Cape Cod, was higher than now during the Tertiary era, as is shown by the presence of submerged Tertiary deposits off the coast (p. 490).

(5.) The height required for the ice-surface, over the Canada watershed, in order that it may have sent a glacier over New England, renders it probable, that part was acquired through an elevation of the land. It may be that the Great Lakes were largely drained, in consequence of the lifting at the north.[1]

The view that the land of Great Britain was above its present level, when the glacier was formed, is urged by Lyell, Dawkins, Geikie, and other British geologists. Erdmann, in his elaborate memoir on the Quaternary of Sweden, observes that the fact of elevation is established by the extent to which rocks were polished beneath the sea level, and that the country was probably so much raised that a large part of the Baltic was dry land. Spitzbergen, according to Nordenskiöld, was so enlarged westward as to reach Scandinavia on the south

[1] The author's views on fiords and the subdivisions of the Quaternary (Post-tertiary) were first published in the *Amer. Jour. Sci.*, II. vii. 379, 1849, and xxii. 325, 346, 1856. The subject is further reviewed and extended in III. i. 1, ii. 233, 1871, and v. 198, 1873, ix. 312, x. 385, xiii. 79.

and continental Siberia on the east. Great Britain was probably at the same time joined to Europe (p. 572), and to the islands on the north. Scotland, as its fiords and the channels between the Hebrides show, must have been at least 1,000 feet above its present level.

2. Source of the Cold. — The subject of the origin of change in climate is treated of on page 714, where some of the sources of cold as well as warm climates are explained. It is important to remember, in this connection, that cold which covers a country with ice has in the ice a source of perpetuation, since, whatever the heat of the sun, no temperature is radiated from the surface higher than that of freezing, or 32° F.

If the cause of the Glacial cold was connected with a closing of the Arctic regions against the tropical currents of the Atlantic (p. 713), the North Atlantic ocean would have had greater warmth than now, and this would have produced unusual evaporation, and hence unusual precipitation on its cold borders.

The theory that makes the era of cold dependent on the earth's being in one of its periods of maximum eccentricity (p. 715), requires that the Glacial era of the southern and northern hemispheres come at different times 11,500 years apart. A source of evidence as to whether there was such an interval or not, exists in the distribution of Quaternary animal and vegetable life; but no facts have yet been observed settling the question.

3. Exterminations and migrations consequent on the approach of the cold period. — The approach of the cold Glacial era probably produced that extermination of species which closed the Tertiary age, besides causing the migration to more southern latitudes of species not exterminated. Some facts illustrating the latter point are mentioned on pages 532, 533. The former hardly needs illustration. The cold must have come on with extremely slow progress. The extermination of the terrestial Tertiary mammals, or such as did not find shelter to the South, may have been an early effect of the progressing refrigeration; and, long before the glacier had reached its limits, species adapted to a more rigorous climate, that is, those of Quaternary times, may have begun to occupy the country.

The Glacial period, which is here shown to have probably been an era of high latitude elevation, was followed by one of unquestioned depression — the Champlain period; and to this period of depression is here referred the closing part of the era of ice, that is, the period of the melting or disappearance of the ice.

2. CHAMPLAIN PERIOD.

1. American.

The Champlain period is so named from the occurrence of beds of the period on the borders of Lake Champlain.

I. General Course of Events.

The earlier part of the Champlain period was the era of the melting of the great glacier, and of most local glaciers; and therefore the era of immense floods along the valleys; of many and great lakes; and of the deposition of the sand and gravel of the glacier, except the relatively small part which had been earlier dropped. While the Glacial period was eminently a period of abrasion and of valley-erosion, and of the gathering and transportation of earth and stones, and also of some deposition along the course of the glacier, and much at its terminus, the Champlain was the era of the general deposition of this earth and stones, and the further distribution of it by inland waters in the excavated valleys and lake-basins, and along sea-borders.

Facts demonstrate, moreover, that the period was not only one of lower level than the present, but, further, that the amount of depression increased northward, so that the beds of rivers flowing southward often had diminished slope in Champlain time, and the waters a slackened flow, with, consequently, many expansions into lakes along their course; and that their exit to the sea was often by long and wide estuaries.

The Champlain period, or era of depression, includes two subdivisions: —

1st. The *Diluvian* epoch, or that of the depositions from the melting glacier, which depositions began when the melting had far advanced (the earth and stones having been in the lower portion of the glacier, and the melting having been general over its surface), and which continued — probably with some interruptions — until the melting had ended. Direct evidence of the final flood is contained in the deposits, as explained beyond, on page 548.

2d. The *Alluvian* epoch, or the part of the era of depression after the melting had ended, characterized by depositions of a more quiet character.

II. Rocks: kinds and distribution.

1. Kinds of deposits. — The deposits of the *Diluvian* division of the Champlain period are of the following kinds: (1) those that were

dropped by the glacier, after the period of melting set in, over the hills where there were no waters to receive them, and which are, therefore, *unstratified;* and (2) those which fell into waters, or where the waters could gather them up for transportation, and which therefore became more or less *stratified.* In other words, the *unstratified* and *stratified Drift*, as stated on page 527, were *deposited* mainly in the Diluvian era of the Champlain period.

To the *Alluvian* era belong the subsequent deposits of the period.

In both eras, there were, outside of Glacial latitudes, and partly within, other formations of various kinds in progress, like those of the present day.

A. *Unstratified Drift.* — The unstratified Drift consists of sand, gravel, stones, lying pell-mell together, as they were thrown down from the melting glacier. The bed of *bowlder-clay*, in progress of deposition during the whole progress of the glacier (p. 527), would have continued to increase through the first part of the melting, and afterward become covered with coarser material. Wherever, in the progress of the deposition over the hills, a temporary run of water was made, some stratification would have ensued; and, if the run was afterward obliterated, the deposition would have been again unstratified.

The vegetable material in the ice would have been dropped whenever the ice relaxed its grasp; and, being in the lower part of the glacier, and often in large amount at a common level, it would naturally have often found lodgment in the lower half of the Drift deposits, either as isolated logs, or as thin beds of vegetable debris.

B. *Stratified Drift and Alluvial Beds.* — The material of the stratified Drift was derived by the waters either (*a*) direct from the melting glacier; or (*b*) from the loose material that remained over the hills after the ice had disappeared; or (*c*), for the later Champlain depositions, in part from subsequent wear and decomposition. The beds were deposited either (1) along the valleys and flooded streams; or (2) in and about flooded lakes; or (3) in estuaries, and along sea-borders; making (1) *Fluvial*, (2) *Lacustrine*, and (3) *Sea-border* formations.

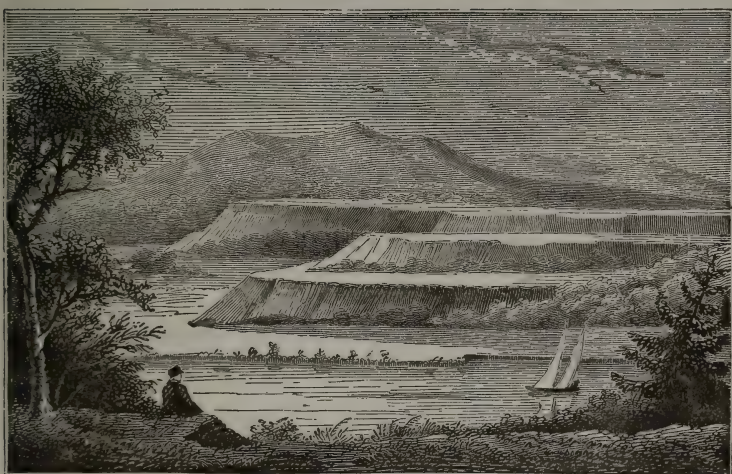
2. Fluvial and Lacustrine Formations. — The formations of river-borders and lake-borders are essentially alike, except that the latter are, to a greater extent, of a clayey nature. The rivers were often lakes at intervals.

1. *Distribution.* — The fluvial and lacustrine formations appear to characterize all the river-valleys and lake-basins of the continent, over the Drift latitudes, and also, to a less extent, those still farther south, so that they may be said to have a continental distribution. The fluvial deposit generally accompanies the whole course of a stream

and its tributaries, to the sources in the mountains, and fails only where the stream is a steep mountain-torrent, or is bounded by lofty walls of rock. A map showing the distribution of the formation over the continent, in Drift latitudes, would hence be much like a map of the rivers, the courses being the same for each; the only exceptions being that the minor bends of the rivers would be absent, and that the breadths would be very much greater. The flood-grounds of some large streams are now miles in width; but, in the Champlain period, the waters often spread to three or four times the distance of any modern flood, besides rising to the high level marked off by the upper plain or terrace.

2. *Topographical features.* — These formations, whether along river valleys or about lakes, have generally a flat summit, because levelled off by the waters. They stand at various heights, the top often one or more hundred feet above the level of the river or the lake adjoining. Commonly, there are plains at several levels, in which case, the

Fig. 941.

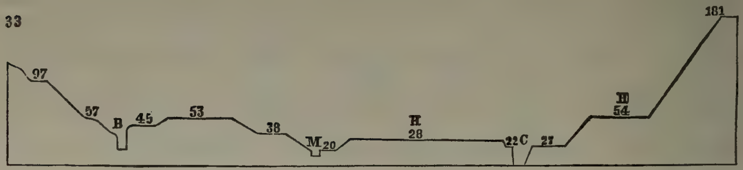


Terraces on the Connecticut River, south of Hanover, N. H.

valley is bordered by a series of terraces. Terraces around lake basins have been significantly called *benches.* The accompanying sketch (Fig. 941), from the Connecticut River valley, some miles south of Hanover, N. H., represents the general appearance of the formation, with its terraced surface. Up and down the stream, horizontal lines may often be traced for miles, marking the limit of one or more of the several terraces bordering it. Many villages in the vicinity of rivers owe a large part of the beauty of their sites to these natural terraces.

The section (Fig. 942) shows the position and heights of the various terraces in the Connecticut valley at Hadley, Mass., as measured by Hitchcock. Some of the levels are about the same on the

Fig. 942.

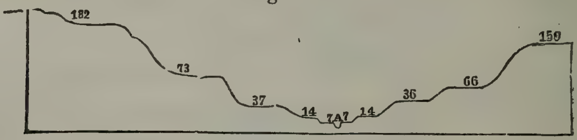


Section of the terraced valley of the Connecticut, at Hadley; B, a brook; M, Mill River; H, Hatfield; C, Connecticut River; H, Hadley.

two sides of the river channel (C), while others on the west are not represented at all on the east side, and one low one on the east has no corresponding level on the west. The terraces in the Ashuelot River valley at Hinsdale, N. H., are represented in Fig. 943; among them there is the same kind of agreement and diversity on the two sides of the stream (A).

In Fig. 942, the Connecticut valley includes the channels of another stream at M, Mill River, and of a brook at B; and all made their contributions of material for terrace-depositions and took part in terrace-shaping. In fact, the material for the formations of a valley, like the

Fig. 943.

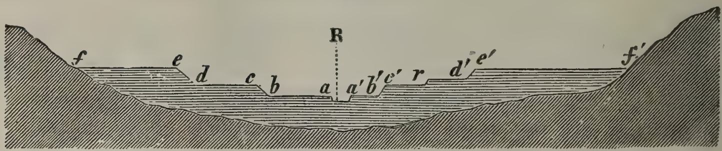


Section of the Valley of the Ashuelot River, at Hinsdale.

Connecticut, always came in very largely through the streams of the smaller valleys either side.

3. *Structure.* — The material of the terraces is usually stratified as

Fig. 944.



Section of a Valley, with its terraces completed.

illustrated in Fig. 944. In this figure, the river channel which it occupies at low water, is at R; *ab*, *a′b′*, are the flats either side which

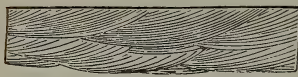
become flooded in modern high freshets; in other words, the flood-grounds; ef, $e'f'$, are the flood-grounds of the river during the great Champlain floods (or what is left of them); and the intermediate terrace-plains are other levels, formed either during the rise of the flood, the water while on the increase flowing long, it may be, at certain levels; or during the decline, which also may have taken place by stages, and have been long in progress. Part may be under-water levels; for great streams and lakes, or lake-borders, often have shoals at two or three levels; and part may have been occasioned by the contributions of side valleys, and unequal resistance to wear.

The stratified beds consist either of clay, earth, sand, gravel, or gravel with a large admixture of cobble-stones or bowlders. Beds of these kinds may alternate with one another, and occur at various intervals in the deposits; but along the larger river valleys, clay deposits are most common toward the bottom, and pebble and cobble-stone beds toward the top. As in other cases, the rate of flow in the waters influenced the nature of the deposit as explained on page 654, and hence the kind of material is an indication of the rate of flow during the deposition. The bed that consists of clay at one place may thence be of sand a few rods off, or have at times interlaminations of sand; and the high-terrace formation, chiefly composed of sand-beds, may be, and often is, topped by the very coarsest of a river valley because of the violence of the floods during their later depositions. The clay deposits are most extensive about lakes, or where the rivers were widened into lakes; and they have usually the thin lamination of ordinary river deposits. Owing to their great extent over the region north of Lake Erie, the beds there have been designated by Logan the Erie clays. These clay deposits may rise but a few feet above modern low-water mark in one part of a valley, and a hundred feet or more in another part; this depending on the shorter or longer continuance of the period of quiet waters, and other conditions. Occasionally such clay beds contain isolated bowlders, a ton, more or less, in weight, and in this, as well as their being overlaid in places by coarser stratified drift, they show that they are true Drift deposits; for only overhanging or floating ice could have dropped to their places such masses of rock. The lower beds of the clay deposits in the region of the Great Lakes have sometimes, at or toward the top, local beds or patches of vegetable debris — as stems, roots, logs, and mosses — blackened but not carbonized, as noticed by Newberry, near Cleveland, Ohio, and earlier by Logan, near the Grand Sable and Goulais Rivers. Since the material earliest deposited from the melting glacier would have been the heavier scratched bowlders, stones, and gravel of its under portion, the very bottom of the valley Drift would naturally be of this

nature. But where the river terraces are extensive, the coarse, lowest bed is seldom in sight, because far too deep for observation except through the sinking of shafts. Either side, approaching the hills which bound the terrace-formation, the depth is less, and often a few yards down, scratched bowlders may be found abundantly. But in the parts of large valleys *where the depth of the water was small*, the cobblestone and bowlder deposit may be in sight, constituting a low terrace along the river valley, or the under portion of the other terrace deposits. Long lines of such coarse and often only semi-stratified material occur along the upper half of the Connecticut and on other rivers and have been called by the Scotch name *kames*.

The stratification which the deposits present varies from the most regular, or that of gently-moving waters, to that which could form *only under a vast simultaneous supply of gravel or sand, and water*. The common form of this Diluvian or *flow-and-plunge* style of deposition is illustrated in the following figure (945), in which the layers are made up of wave-like parts, corresponding to successive plunges in the rapidly flowing waters. Beds of this kind occur with others of horizontal bedding; or sometimes locally in the midst of coarse gravel deposits, such stony gravel not participating in it because of its coarseness.

Fig. 945.



In many large valleys the formation is the earthy lœss, a deposit sometimes of great thickness; it indicates, by the absence of bedding, that it was made in a prolonged flood with the waters comparatively quiet, and not in violent flow; for the floods of successive years would have left marks of the succession in the bedding; and violent movement would have made oblique lamination. (See further, p. 660).

The most remarkable of these river-valley formations is that of the great valley of the continent, the Mississippi. As shown by Hilgard, the beds — called by him Orange-sand beds — extend down both sides of the valley, from Kentucky and Missouri to the Gulf; and, below Natchez, the formation stretches eastward into Alabama, and westward into Texas. They consist mainly of sand, but include some pebbly beds, the principal one in the lower part of the valley being at the bottom; and occasionally they contain, even in Mississippi, stones of ten to one hundred pounds in weight, and rarely one hundred and fifty pounds. There are also some local clayey beds. The stones show that the material came from the northward; many have in them Paleozoic fossils. The beds have generally the *flow-and-plunge* structure, illustrated in Fig. 942. The facts prove that there was a vast and violent flow of waters down the Mississippi valley, bearing an immense amount of coarse detritus; a result commensurate with the

width of the glacier that lay over the upper part of the great valley west of the Appalachians, and the extent of local glacier centres in the Rocky Mountains. Part of the transportation must have been due to floating ice from the dissolving glacier.

The "Orange sand" is 40 to 100 feet thick, and in some places over 200. Toward the Gulf, it lies at considerable depth below the water level. In an Artesian well, near the Calcasieu River (two hundred miles west of New Orleans), the Orange sand was 173 feet thick, beneath 160 of clay (Port Hudson group); and at another, seven hundred yards to the west, 96 feet thick, beneath 354 feet of clay. These and the other facts respecting the Orange sand are cited mainly from Hilgard's papers. In Tennessee, the beds are called by Safford the "Bluff gravel;" they overlie, in part, Eocene or Cretaceous beds, as they do also farther south.

4. *Alluvian Deposits.* — The Diluvian beds along rivers and about lakes are often overlaid by others, whose texture indicates more quiet deposition. The floods were of long duration, owing to the very slow retreat of the glaciers, and the continued depressed level of the land; and hence the lakes were still many and large. and the rivers of great breadth, though after a while somewhat diminished, from the lessened supply of water. Floating ice from the north may long have aided in transportation of earth and bowlders. Wherever the *Diluvian* formation was not built up to the level of the flood-waters, new beds were deposited, mostly of earth or loam, making the alluvial beds or *lœss* of the river borders; but, in other places, of sand and coarse material, according to the rate of flow of the waters.

Sand and fresh-water shells, teeth and bones of Quaternary Mammals, leaves and other relics would naturally exist in deposits then made; and peat-beds may have been formed in marshes, and afterward become buried under new deposits in progress.

Frequently, the Diluvian depositions filled the depression to the water level *along the sides* of the valley (or lake basin), but left a wide area either side of the river bed at a lower level; and over this part the Alluvian depositions were made, and the whole finally brought up to one plain. These are points to be considered in judging of the relative ages of the different parts of any Champlain deposit, whether fluvial, lacustrine, or marine. The lœss is best developed on large streams.

In the Mississippi valley, it covers the "Orange sand," forming with it the "Bluff formation" — so called because standing in bluffs in Missouri and also on the east of the Mississippi flats. In Tipton County, Tennessee, there are (over about ninety feet of Lignitic Tertiary) 24 to 40 feet of Orange sand or "Bluff gravel," and 45 to 68 of Bluff loam, or lœss. (Safford.) The formation in Mississippi and Louisiana has been called by Hilgard the "Port Hudson Group." It contains, like the lœss of the Rhine, some carbonate of lime, partly in concretions, due to fresh-water shells mixed in powder with the earth. At intervals, it has layers of marsh material, including Cypress stumps imbedded in laminated clays; and south of New Orleans there are marine shells. As the Orange-sand deposits lie at considerable depth toward the Gulf, the Port Hudson deposit has a thickness in some places of several hundred feet; and, where this is the case, the lower part may be the equivalent of a portion of the Orange sand. Above the Port Hudson group, and a deposit overlying it, thirty to seventy feet thick, without bedding, distinguished as "lœss" by Hilgard, there is generally a thin deposit of yellow loam.

A peat bed of the Alluvian era, a mile east of Germantown, Montgomery County, Ohio, has been described by Prof. Edward Orton.

The lœss of the Mississippi contains numerous fresh-water shells, among them *Paludina ponderosa* Say, *Melania canaliculata* Say, *Cyclas rivularis* Say, *Cyclostoma lapidaria* Say, *Physa heterostropha* Say, *Limnæa elongata* Say, *Planorbis bicarinata* Say, *Valvata tricarinata* Say, *Unios*, etc.

5. *Upper level of the terrace formations.* — The height of the river-border formations above modern flood-level often increases to the northward — floods having been greater where the ice was thickest. On the Connecticut, the height at Middletown, Ct., is 150 feet; at Springfield, Mass., 180 feet; at Hanover, N. H., 240 feet. On Lake Ontario and the Great Lakes the terraces are 300 to 500 feet high.

But the level varies according to (1) the varying pitch of the bed, (2) the varying width of the valley, and (3) any obstructions encountered, — increasing pitch and width of valley tending to diminish height, and *vice versa;* and obstructions (whether proceeding from a narrowing of the valley, or from impediments due to rocky ledges in the way, or to amount of detritus under transportation) causing a rising of the level of the floods, and therefore of the terraces or flood-deposits.

Again, where narrows existed at which transported ice or drift could dam the stream, the terraces above the narrows have an extraordinary height; and, then, below the narrows, there is a rapid fall off in level. The height of 150 feet on the Connecticut at Middletown, was occasioned by such a dam; for south of the narrows the height decreases at a mean rate of five feet a mile, and the height at the mouth of the river, on Long Island Sound, is less than fifteen feet. Further, small streams, receiving little water, would have had low terraces under any circumstances.

Stevenson has described very high broad terraces in Western Pennsylvania, the origin of which has not yet been fully explained. (Am. Jour. Sci., 1878.)

Heights of Upper Terraces, east of Rocky Mountains, above the level of rivers or lakes. — On the coast, along the southern borders of New England, 10 to 25 feet. On the Thames, in Eastern Connecticut, the terrace at its mouth is not distinct; 3 miles above, near New London, the height is 25 feet; from there it rises 5 feet a mile to the narrows below Norwich, where there must have been a dam, as on the Connecticut; and at Norwich, above the narrows, the height of the plain is 100 to 117 feet. The sandy terrace between Schenectady and Albany, N. Y., and opposite the latter place, east of the Hudson, is 330 to 335 feet above the river. On the Genesee, east of Portage, the upper level is 235 feet above the river.

The ridge road or terrace, south of Lake Ontario, 190 feet above the lake, the greatest height (Hall); terrace south and southwest of Lake Erie, 220 feet; north of Lake Ontario, at Toronto and other points, 30 to over 500 feet; the Davenport ridge, west of Toronto, 250 to 300 feet; west of Dundas, west end of Lake Ontario, 318 feet (under the escarpment of the Niagara formation, which is 100 feet higher); near Fredericton, New Brunswick, on the St. Johns, 345 feet above the river; at other points below, on the

same river, 350 to 400 feet. On the north side of Lake Superior, the maximum reported, 331 feet above the lake; near Lake Huron, clayey deposits, at different levels up to about 500 feet. On the Lower Ohio, 50 to 160 feet; near Louisville, 52 and 128 feet above low water, or 10 and 86 feet above high water: near Cincinnati, 100 to 120 feet above low water. On the Mississippi, in Tennessee, 50 to 180 feet; at Fort Adams, Loftus Heights, 163 feet (made up of 90 feet of Orange Sand and 73 of lœss); at New Orleans, about 60 feet. On the Missouri, in Platte County (N. W. Missouri), 335 to 150 feet. Atchison County, 250 to 150 feet. On the Red River, in Texas, 50 to 100 feet.

About Lake Winnipeg, one of 75 to 100 feet above the lake; a second of 300 to 350 feet (at Pembina mountain, west of Red River) (Hector).

In the Rocky Mountains (*where part of the terraces are true moraines*) *and to the west of summit.* — On the Athabasca and Saskatchewan, 300 to 370 feet; and on Bow River, 350 feet (Hector). At an elevation of about 6,000 feet above sea level, along the valley of the Madison River, Montana, 243 feet (Hayden). At nearly 7,000 feet, south of Jackson Lake, head-waters of Snake River, about 400 feet (F. H. Bradley). About Great Salt Lake, Utah, 900 feet; on Marsh Creek, Idaho (one of the old outlets of Great Salt Lake), 1,000 feet (F. H. Bradley); La Plata Creek, branch of Arkansas (moraine), 800 feet (Hayden); on Clear Creek, another branch (moraine), 600 to 800 feet (Hayden); Roche Moutonnée Creek, branch of Eagle River (Fig. 1106), on both sides of valley (moraine), 937 feet (Hayden).

In and west of the Sierra Nevada, and its continuation north.— Mono Lake (salt-water), 385 and 680 feet above the lake; King's River (moraine), 1,500 feet (Whitney); Bloody Cañon, near the Yosemite (moraine), 500 feet; Hope Valley, ibid., 600 feet; Lake Tahoe (moraine), 1,600 (?) feet (Leconte); Island of St. Nicholas, northeastern side, 30, 80, and 300 feet; Santa Monica Cañon, where it reaches the coast, 15 miles from Los Angeles, 148 and 175 feet; north side of Pajaro valley, on seashore, south of Monterey, 263 feet; on the Nascimiento River, 20, 80, and 187 feet; on the Salinas River, for 80 miles from its mouth, from 125 to 150 feet; on the Arroyo Joaquin Soto, a branch of the San Benito, in the Mt. Diablo range, 225 feet; on the Sacramento River, near Red Bluff, 80 to 100 feet (Whitney); on the Willamette, Oregon, 50 to 85 feet; on Frazer's River, British Columbia, near Lillooett (122° W.), 500 or 600 feet (Begbie); on the Kootanie and Upper Columbia, 600 feet (Hector); on Canoe River, a northern branch of the Columbia, 400 feet (Selwyn).

The moraines, in the Rocky Mountain region, are evidence of the level of the end of the glacier, and not of that of a river terrace. A moraine on Texas Creek, Colorado, 600 feet high, fades out in eight miles. Those on Clear Creek, Colorado, 600 to 800 feet above the present stream, fall to 100 feet in six miles. (Hayden and Gardner.)

About New Haven, Connecticut, there is a good exhibition of the deposits that were made by the flood in an estuary or bay. The beds are, for the most part, obliquely laminated; and the laminæ *rise to the north*, that is, pitch in the direction of the flow. Further, the effect of plunges in the waters is apparent in the flow-and-plunge structure of the obliquely-laminated beds. (Fig. 945.) Such beds are usually as much as six inches thick, but occasionally *six to eight feet.* A thickness even of six inches is proof that vast amounts of sand and gravel were at the disposal of the currents and waves, and that the deposition went forward with great rapidity.

6. *Relation to the Level of the Ocean.* — In the position of the upper limit of the *river-border formations*, there is no direct relation to the level of the ocean. They were made by flooded rivers or lakes; and the height of the flood-waters determined their level. The streams over plateaus or slopes, 2,000 feet above the ocean, would have made deposits at that height, *plus* the height of the flood above it.

3. Sea-border Formations.—On sea-borders, the formations are, in general, similar to those of lake-basins and valleys, except that they

often contain marine fossils. The seashore terrace or "bench" is often the termination of a river-border terrace, one graduating into the other, the river level and sea level being the same at the mouth of a stream. They are commonly called *elevated* beaches, though not always of beach origin. Like lake-border formations, they are, in many cases, combinations of Diluvian and Alluvian depositions; but, besides beds made in shallow waters, containing shallow water fossils, there are often others of deeper-water formation, different in most of their marine fossils. They vary also according as they were made on an open coast or in an estuary.

The *height of the sea-border formations* increases with the latitude. On the southern shores of New England, the height above the sea is 10 to 25 feet; on Nantucket, 85 feet; at Point Shirley, near Boston, 75 to 100 feet; on the coast of Maine, in some places, 217 feet; on the shores of Lake Champlain, at different heights, up to 393 feet above tide-level, and containing marine shells to a height of 325 feet; on the borders of the St. Lawrence, with abundant marine fossils, near Montreal, to a height of 470 feet; from which point, the same formations continue on, and border Lake Ontario; but they are destitute of marine remains, — the flow of fresh waters in the river St. Lawrence beyond having apparently prevented the farther ingress of the ocean and of marine life. On the coast of Labrador, the beds are 400 to 500 feet above the sea. They occur also in the Arctic regions in many places, as on Cornwallis and Beechy Islands in Barrow Straits, where they are at different heights to more than 1,000 feet.

The seashore deposits on Nantucket occur at Sancati Head. In Maine, the beds occur at many places near the coast, as Portland, Cumberland, Brunswick, Thomaston, Cherryfield, Lubec, Perry, etc., at different elevations, not exceeding 217 feet, so far as yet reported; also distant from the coast, at Gardiner, Hallowell, Lewiston, Skowhegan, Clinton Falls, and Bangor. At Lewiston, a starfish and various shells were found in a bed 200 feet above the ocean and 100 above the Androscoggin River; at Skowhegan, the beds are 150 feet above the ocean, and 100 feet at Bangor; near Mt. Desert (a sea-bottom deposit, on North Haven Island), 217 feet.

There are shell-beds at several levels and many localities, along the St. Lawrence, observed by Logan; and part, as Dawson has shown, are sea-beaches, and others off-shore deposits. At Montreal, at heights of 470, 420, 366, 200, 100, above the river, or 20 feet more for each above Lake St. Peter; west of Montreal, near Kemptville, at a height of 250 feet; on the Upper Ottawa, 65 miles northwest of Ogdensburg, 360 feet; in Winchester, 300; in Kenyon, 270; in Lochiel, 264 and 290; at Hobbes Falls in Fitzroy, 350; at Dulham Mills, 289; in the counties of Renfrew, Lanark, Carlton, and Leeds, 425; east of Montreal, near Upton Station, 257; farther east, on the river Gouffre, near Murray Bay, 130 and 360 feet. At the Straits of Belle Isle, Labrador, the terraces, on either side, are about 400 feet above the sea; at Chateau Bay, 500 feet, probably 800 feet in some parts (Packard).

The 100-foot level near Montreal was apparently beneath the sea at the time, as the shells in which it abounds are not littoral species, neither are the specimens water-worn. At Beauport, near Quebec, there are thick beds of this kind, mostly made of shells, partly littoral, and situated at heights of 200 to 400 feet above the sea. The depth of

water inferred for these deep-sea beds by Dawson, from the species of shells, is 100 to 300 feet. Dawson makes the marine formation in Canada to consist (1) of unstratified bowlder-clay; (2) deep-water clays just mentioned, called *Leda clays*, from one of the fossils; (3) the overlying shallow-water sands and gravels, called also the *Saxicava sands*.

The more common shells of the Montreal beds are the following (Dawson): *Saxicava Arctica* Desh., *Mya truncata* Linn., *M. arenaria* Linn., *Macoma fragilis* Adams, *M. sabulosa* Mörch, *Astarte Laurentiana* Daws., *Mytilus edulis* Linn., *Natica clausa* Brod., *Yoldia Glacialis* Gray, *Trophon clathratum* Mörch, *Buccinum Grœnlandicum* Hancock.

Among the Beauport species, there are the following: *Lunatia Grœnlandica* Adams, *L. heros* Adams, *Turritella erosa* Couth., *Scalaria Grœnlandica* Perry, *Litorina palliata* Verr., *Serripes Grœnlandicus* Beck, *Cardium Islandicum* Chemn., *Pecten Islandicus* Chemn., *Rhynchonella psittacea* Gm., and many others. All are cold-water species, so that the fauna is more Arctic in character than that of Montreal, corresponding with the fact that Montreal is 150 miles northwest of Beauport (Dawson).

The coast of Maine has afforded (Packard): *Pholas crispata* Linn., *Saxicava Arctica, Mya truncata, M. arenaria, Thracia Conradi* Couth., *Macoma fragilis, M. sabulosa, Mactra ovalis* Gould, *Astarte Banksii* Leach, *A. elliptica* Brown, *A. Arctica* Möller, *Cardium Islandicum, Serripes Grœnlandicus, Leda pernula* Müll., *L. minuta* Fabr., *Yoldia glacialis, Pecten Grœnlandicus* Sow., *P. Islandicus, Natica clausa, Lunatia heros, L. Grœnlandica*, etc.

The species thus far discovered, with perhaps one or two exceptions, are identical with those now inhabiting the Labrador seas. They number over two hundred.

The *Capelin* (*Mallotus villosus* Cuv., a common fish on the Labrador coast) has been found fossil on the Chaudière Lake in Canada, 183 feet above Lake St. Peter; on the Madawaska, 206 feet; at Fort Colonge Lake, 365 feet.

On the Bay of Fundy, at Goose Creek, there are several levels of beaches, up to a height of 490 feet. (Hind.) On the coast of Labrador, the elevated Champlain beds contain mostly the same species, both those of the Leda clays and the overlying beds. Among the species less abundant farther south, or not at all, are *Cyclocardia borealis* Con., *Astarte Banksii, Margarita varicosa* Mighels, *Turritella reticulata* Mighels, *T. erosa, Aporrhais occidentalis* Beck, *Admete viridula* Stp., *Bela exarata* Müll., *B. harpularia* Adams., *B. robusta* Pack., *B. turricula* Montf., *Fusus tornatus* Gld., *F. Labradorensis* Pack., *Buccinum undatum* Linn. (Packard.)

South of Cape Cod, at Sancati Head on Nantucket, and at Gardner's Island, the species were the *warm-water* kinds, now inhabiting this region, and not the subarctic that existed north of the Cape.

On the Pacific side, there are shell-bearing sea-border beds, at San Louis Obispo and San Pedro, 80 or 90 feet above the sea, and at higher levels (Newberry); on north bank of Lobos Creek, and west of Black Point, near San Francisco, 80 to 100 feet. Terraces occur also about Sonora, Mexico.

III. General Observations.

1. *Geographical Conditions in North America due to the subsidence.* — The elevated *sea-border* formations that have been described prove that, in the Champlain period, the land, where such formations occur, was at the water's level. They show, for example, that southern New England was 10 to 25 feet below its present level; Sancati Head, on Nantucket, 85 feet; the coast region of Maine, in some parts, 217 feet; the borders of Lake Champlain, between 350 and 400 feet; the region of the St. Lawrence, along by Montreal, nearly 500 feet; about the Bay of Fundy, 350 to 400 feet; the Labrador coast, 400 to 500 feet; parts of the Arctic regions, over 1,000 feet.

It is probable that nearly or quite the whole breadth of the continent was similarly depressed, and that its amount was greatest to the north. We cannot account for the terraces of Lake Ontario by supposing a damming of the St. Lawrence by ice; for they are much higher on the northern side of the lake than on the southern; and the terrace, nearly 500 feet above the St. Lawrence, which is shell-bearing at Montreal, may be traced along at intervals to the northern borders of the lake, proving unbroken communication at the time, and a vast outflow of water. Admitting the submergence, and its increase in amount northward, the inequality in the level of the terraces on the north and south sides of a lake gives no difficulty.

The subsidence, although so general, could not have been due to any cause affecting the whole ocean; for the difference in amount of subsidence between Southern New England and the region of Montreal, only $6\frac{1}{2}$ degrees apart, was 450 feet, and between the coast of Maine and Montreal, one degree apart, 275 feet. It was a change affecting locally the earth's crust, and large portions at once, over the higher latitudes.

We hence learn that, in the Champlain era, salt waters spread over a large coast-region of Maine, and up the St. Lawrence nearly to Lake Ontario, and covered also Lake Champlain and its borders. This great arm of the sea, full 500 feet deep at Montreal and 300 to 400 in Lake Champlain, was frequented by Whales and Seals, their remains having been found near Montreal, and a large part of the skeleton of a Whale — *Beluga Vermontana* Thompson (Fig. 950) — having been dug up on the borders of Lake Champlain, 60 feet above its level, or 150 feet above that of the ocean. It appears, besides, that Nova Scotia was, at the same time, an island, and that the cold Labrador oceanic current crossed the present isthmus (now less than 20 feet above high tide at Cumberland basin) with a depth of water exceeding 350 feet, and thence flowed down the Bay of Fundy to the coast of Maine and eastern Massachusetts, bringing with it the living species of the Labrador seas.

It has also to be borne in mind, that, as stated on p. 543, the greater depression of the land to the north must have caused a diminished pitch in the bed of southward flowing streams; and that this would have influenced largely the height and breadth and pitch of flood-level and of flood-made depositions, and, also, the degree of fineness of the deposits. It would have favored fine clayey depositions in many parts of valleys, until the flood, with increased height, had quickened the rate of flow. The bed of the Hudson River at Albany is now at high-tide level; but in the Champlain period, judging from the depression of Lake Champlain, it was nearly 150 feet below this. A study of the

deposits in this and other valleys may yet give the actual amount of depression.

2. *Conditions due to the supply of Fresh Water. The Final Flood from the melting of the Glacier.* — That the melting of the glacier should have ended in a great flood may be inferred from the common observation that in cold latitudes floods terminate ordinary snowy winters.

The subsidence of northern lands would have brought on the conditions of a warmer climate; and, as the melting went slowly forward, this amelioration must finally have become very decided. Consequently, there was melting, not merely along the southern edge of the glacier, but over its wide surface; and, when the thickness of the ice was at last reduced to a few hundreds of feet, and it had become rotten throughout, the melting must have gone forward with greatly augmented rapidity; and a flood, filling rivers and lakes to an unwonted height, must inevitably have followed.

The fact that such a flood, vast beyond conception, was the final event in the history of the glacier, is apparent in the peculiar stratification of the flood-made deposits, described above (p. 548); and it is strikingly manifested in the spread of the stratified Drift southward along the Mississippi valley to the Gulf, as first made known by Hilgard. Only under the rapid contribution of immense amounts of sand and gravel and of water from so unlimited a source, could such deposits have been accumulated.

There is direct evidence, as already implied, that the flood reached a maximum just before the close of the melting. In some of the New England estuaries of the Champlain era, as that of New Haven, and along many of its river valleys, the stratified deposits are mainly of sand and small pebbles until within fifteen or twenty feet of the top; but above this limit there is often a sudden change to gravel and sometimes very coarse gravel or cobble-stone beds; a change which indicates that, when the flood was at its height, the torrent bore away most of the sand, leaving the stones. The coarse upper stratum is usually overlaid by a yard or two of finer material.

The sand deposits which succeed the "Erie Clays," in the region of the Great Lakes, may be evidence of the flood over those regions. The logs and vegetable debris, which in some spots top the clay beds, may be additional proof of the loosened grasp of the ice. The depositions of Orange sand along the Mississippi valley probably took place at this time of maximum flood.

The flood would have continued long into the Alluvian era, on account of the ice to the north, yet with much abatement of its violence. Even till near its close, the melting glacier about the northern margin

of the Great Lake region may have sent off floating masses down the Mississippi valley, as well as to parts of the present prairie region of Ohio, Indiana, and Illinois.

The facts teach, that the region of the Great Lakes was probably one immense lake, as held by Newberry and others, and that the waters spread far south, over the States of Ohio, Indiana, and Illinois, and discharged from Lake Erie and Lake Michigan into the Mississippi valley, so that there was abundant opportunity for transportation, by means of floating ice, from the Glacier to the Gulf. We gather also that the Mississippi waters of the Champlain era, below the mouth of the Ohio, had *an average breadth of fifty miles*, and, along by Tennessee and northern Mississippi, of *seventy-five miles ;* so that it was indeed a great stream. In the Glacial period, the era of erosion, it was deepening its bed, through the Paleozoic, Cretaceous, and Tertiary rocks; but, in the Champlain, when the land to the north was depressed, the river filled full the wide valley, and made its great breadth of Champlain deposits. All the other rivers of the continent, alike augmented, were at the same work, each according to its capacity. The Connecticut River south of Northampton had two great channels thence to the Sound, both 80 miles long, and 100 feet or more in depth (the old one 150 to 200 feet) the most of the way ; while the new western one emptied into New Haven Bay by two river-courses, those of Mill River and the Quinnipiac. (Am. Jour. Sci., III. x. 477.) The Champlain period, in the world's history, was preëminently the era of fresh-water formations.

Other geographical changes from the Champlain flood consisted in the filling up of old river-channels with drift, and forcing the streams to open new ones. There is an old gorge of Niagara River, commencing at the Whirlpool, which was thus filled. It is probable that, when the damming by Drift was accomplished, the waters of Lakes Erie and Ontario were on a common level, so that there was no river-flow to prevent the catastrophe ; and that, when the elevation that ended the Champlain era began, the river first found out that its old channel was gone. The stream, then renewing its flow, began, at the Queenstown heights, the present cut through the rocks to the Whirlpool (p. 590).

Dr. Newberry has stated that the Ohio River formerly had a more southern channel around the Falls, near Louisville, and lost it, in a similar way, in the Champlain period; that formerly Lake Huron discharged into Lake Erie by a more easterly channel than the present one, and was forced in this era to take the route over the rocks. The channel of discharge, from Lake Michigan to the Mississippi, which F. H. Bradley has pointed out as having been made or used in the Glacial period, he shows was filled up in the Champlain, and then the more western channel, from Chicago along the Des Plaines to the Illinois, became the outlet, and continued to be so until the elevation opening the Recent period.

3. *The height of the upper terrace of river valleys and lakes was largely an effect of the height of the flood, and not necessarily of a subsequent change of level in the continent.* — So enormous was the supply of water that where now the river floods rise to 25 feet, they rose then, in many cases, to 100, and sometimes to 250 feet or more. At these heights the upper terraces were made, and hence they mark approximately the upper flood-level. The flood caused an increase in the pitch of the stream on an average probably of a foot a mile, and not uncommonly of five feet for small obstructed streams. In Southern New England the change of level — 10 to 25 feet — which has since taken place, may have affected this much the height as far up the rivers as tide-level extended, but only little, when any, beyond this point. The St. Lawrence was one of the great rivers, whose terraces are for a long distance due almost solely to the elevation of the land. But this was true only so far up the river as the open ocean and oceanic life entered. Above this point the level of the waters was raised by the floods from the back country, and the height of the terraces was consequently due in part to the height of the flood. About the upper of the Great Lakes, the flood was almost, if not quite, the sole cause of the height, as has been urged by N. H. Winchell.

The waters of the Connecticut at Hartford, 45 miles (in an air-line) from its mouth are, when low, at mean tide-level. The river rises 30 feet at its highest modern floods; but it rose 180 feet during the Glacial flood, all but 10 to 15 feet due to the greatness of flood, and the damming by ice at the Narrows below Middletown. The obstructions at the Narrows have the same effect now, as then, but vastly less. In the case of one of the rivers emptying at New Haven, Conn. (Mill River), the terraces 11½ miles from the Sound have a height of 115 feet above the sea-level, indicating a pitch in the flood-waters of 10 feet a mile; but here the valley was shallow and rather broad and the waters were greatly obstructed by the sand and gravel given them to transport.

The Mississippi waters, from the mouth of the Ohio to the Gulf (550 miles), have at high water a pitch of about six inches to the mile; the level at high water adds, at the Ohio, fifty feet to the height. If the supply of waters were sufficient to increase the slope to eleven inches per mile, the height of water would be great enough to deposit all the lœss at its present level. But the land was probably depressed, in the latitude of the Ohio, at least fifty feet below the present level; and, in that case, with less than *nine* inches to the mile, the existing Champlain depositions could have been made. Much greater changes of level actually took place, in the vicinity of the Gulf, according to Hilgard (Am. Jour. Sci., II. xlviii. 331, and III. ii. 398).

The subsiding of the flood and the drying up of the waters were attended with great changes in the surface of the continent. The immense interior lake became the five Great Lakes, and hundreds of smaller lakes along the rivers and elsewhere disappeared. The Kankakee Swamp country, 25 miles wide and 50 long, in Western Indiana, is described by F. H. Bradley as one of these obliterated lakes. The rivers dwindled to one tenth their former magnitude and became narrow threads of water, with contracted flood-grounds between the wide terraced alluvial plains which had been their flood-limits.

4. *Exterminations by the Cold Waters.* — While the reënforced Labrador current of the Diluvian era drove Arctic and Subarctic marine species southward along the northern coasts, the ice and ice-cold waters of rivers carried destruction to the life of more southern seas. Professor Hilgard states that the Orange sand or stratified Drift of the Mississippi valley, where it enters the Mexican Gulf, contains no traces of marine fossils, and for the reason that the great ice-cold stream was like a Labrador current let loose in the Tropics. The estuary and shore deposits about New Haven, Connecticut, are equally destitute of marine shells, and for the good reason that Long Island Sound was actually occupied with ice, whether the land were more elevated than now or not.

B. Champlain Period in Foreign Countries.

The Glacial period of Britain and Europe was followed, as in America, by an era (the Champlain) in which the land stood below its present level, and extensive beds of stratified Drift, overlaid and somewhat interstratified by others of more quiet deposition, were made along sea-borders, lake-borders, and river valleys. The sea-border formations of Sweden and Norway are closely like those of the coasts of Maine and the St. Lawrence, even to the "*Leda clays*" and "*Saxicava sands*." And the valleys of Europe, especially over its northern half, have their extensive river-border formations, which are equivalents of those along the American river-valleys.

Lyell states that the facts lead to the inference that, after the period of elevation with which the Glacial era began, there "succeeded a period of depression and partial submergence," and of accumulations of sand and bowlder-clay, with peaty clay in a few places. This depression in Great Britain varied in different parts from 1,300 to 500 feet, except over southern England, where it may have been only 100 or 200 feet. In Sweden, the depression varied from 200 feet in the south to 400 or 500 in the north; and Erdmann proves that the Baltic was connected with the North Sea, over the region of lakes from Stockholm westward, and with the Arctic ocean by a great channel leading northeastward over Finland to the White Sea. It is even probable that the Caspian and Aral Lakes at this time communicated with the Northern Ocean.

The facts from Europe confirm the conclusion from America, that the Champlain period was the era of flooded rivers and lakes, and of the most extensive fresh-water formations in the world's history. Dupont states that with the close of the floods the flood-grounds of the river Meuse, near Dinant in Belgium, were diminished in breadth from seven and a half miles to a fourth of a mile; and this is an example of the general change over Europe. Europe also had rivers dammed

up by gravel and sand from the unlading glacier.. It has been shown that the Rhine owes its present channel at the Falls at Schaffhausen to its having been forced out of an older one; and it is probable that the Champlain period was the time of the catastrophe.

The depression ten miles east of Glasgow was at least 524 feet, as indicated by the presence of marine shells in beds of clay, which are overlaid as well as underlaid by beds of till. The marine shells present are those mainly of Arctic seas, like the St. Lawrence species. Among them are *Saxicava Arctica*, *Pecten Islandicus*, *Natica clausa*, *Trophon clathratum*, *Yoldia glacialis*, *Macoma sabulosa*. In some parts of Wales, Ireland, and the northern half of England, it appears to have been 1,000 to 1,400 feet, stratified Drift with marine northern shells occurring at this height on the south side of the Menai straits; also at a height of 1,300 feet, on Moel Tryfaen; 1,200 feet, at Macclesfield in Central England; 1,000 to 1,200 feet, in Ireland, County Wexford, south of Dublin; at a height of 568 feet, near Blackpool in Lancashire, fifty miles from the sea. In the depression separating Wales and England — Murchison's "Severn Straits" — beds of marine shells are found at a height of 100 feet.

The lake and river terraces in Great Britain, and especially its northern part, Scotland, are on a scale as grand as the sea-shore deposits. The "benches" of Glen Roy are an example of them. The upper terrace is 1,139 feet above tide-level; the second, 1,059 feet; the third, 847 feet. This is one among many cases that might be cited. As a general thing, the elevated sea-border formations occur on the coasts of regions whose interior is diversified with high lake and river terraces.

A deposit generally regarded as among the earlier Quaternary of Britain, or transitional between the Pliocene and Quaternary, is called the "Cromer Forest Bed"; it is traced for over forty miles along the Norfolk Cliffs, between Cromer and Kessingland, beneath Drift. It contains remains of plants, insects, and shells of living species, along with the remains of some Pliocene as well as many extinct Quaternary species, and some modern Mammals (p. 571).

The sea-border shell-bearing deposits of southern Sweden have a maximum height of 200 feet; of western, 200 to 500 feet, and mostly 325 to 400 feet (Erdmann); those of the northwest coast of Norway, in Hardanger, 293 to 331 feet (Sexe).

The valley of the Rhine and those of its tributaries contain extensive deposits of this Champlain era. The material of the alluvium is mostly the *lœss*, a fine yellowish-gray loam, much of it unstratified, — generally a little calcareous from pulverized shells; and in some parts it contains glacially-marked stones. It rests in some places on stratified gravel or sand. Between Basle and Binnen, this alluvium near Basle has a height of 660 feet above the river; and through much of it there are land and fresh-water shells. The lœss may be in part a deposition from the floods consequent on a second glacial epoch, mentioned beyond (p. 561). Similar facts are reported from most of the river valleys of Europe. The deposits on the Danube are as extensive as those of the Rhine; and Professor Suess states that stones occur in it that were probably dropped by floating ice.

In Belgium, according to Dupont, along the valley of the Lesse, and others, the limestone caverns situated at the greatest elevations — eighty to one hundred feet above the present river — are those which contain the *older* remains of Mammals; and those below are successively more recent as their height is less. Moreover, the river alluvium shows that, when the upper caves were inhabited, the valley was filled with water and river-border deposits, nearly to the level of the cave. Thus the change of level, which marked the close of the Champlain period and the introduction of the Recent period, is very strikingly exhibited.

3. RECENT PERIOD.

The Recent Period is divided into (1) the Reindeer, or Second Glacial era; and (2) the Modern era.

I. Rocks: kinds and distribution.

The formations are such as are found now in progress, either over the land, along sea-borders, or in seas: —

Of Mechanical Origin. — 1. *Continental.* — Alluvial beds along rivers and about lakes; drift sands or dunes; glacial drift, but from local glaciers. 2. *Marine.* — Estuary and delta formations; sea-beach accumulations; off-shore deposits of detritus carried into the ocean by rivers, or made from the battering of cliffs by the waves.

Of Chemical Origin. — Stalactitic and stalagmitic accumulations in caverns (p. 70), the latter often covering the floors of caverns to a considerable depth, and enveloping relics of their former inhabitants; travertine deposits (p. 707); siliceous deposits of hot springs, as those of Yellowstone Park, and, with these, silicified wood, leaves, insects, etc.; deposits of bog iron ores in marshes, with often iron-ore fossils of fruits, stems, etc.

Of Organic Origin. — Peat beds (p. 616); deposits of shells and shell-limestone in lakes, or on seashores; coral-reef formations (p. 620); deposits of Rhizopod shells, over the ocean's bed (p. 611); siliceous deposits, consisting of Diatoms, or of these and the spicules of Sponges, either in fresh water, or in the ocean; deposits of guano, or bird excrements.

Of Igneous Origin. — Lavas, and other rocks of igneous ejections, either from volcanoes or through fissures, comprising both doleritic and trachytic kinds, but chiefly the former.

The formations here enumerated are not always distinguishable from those of the Champlain period. The shells and corals afford no means of distinction, except on certain coasts, where there has been a change of oceanic temperature; but remains of Mammals, and especially relics of Man, when these are present, sometimes afford assistance; and so, also, the peculiar structure of the sand accumulations and their geographical distribution.

II. Reindeer and Modern eras in North America.

The Recent period is separated from the Champlain, by an *elevation* of the land over the higher latitudes, — that is, of nearly the same area that was depressed in the Champlain period. As the Champlain depression was greatest to the north, so it was with the elevation following it; for the height at which the Champlain deposits now stand over the continent, from the southern Drift-limit to the Arctic, is a con-

sequence of this elevation. Terraces exist along the St. Lawrence, Lake Champlain, the coast of Maine, and other parts of the North American coast excepting its more southern portions; and these were a consequence of the changes of level, and are testimony as to the amount of this change. The evidences of a Champlain depression below the present level (p. 550) are evidences that an elevation of the same amount has since taken place.

This elevation made important changes in American Geography. The Arctic, Labrador, and New England coasts gained much in extent, and so also some parts of the Pacific border. Nova Scotia became again part of the main land. The beds of rivers flowing south had their pitch increased to its present amount. The river channels within tidal limits were excavated to a deeper level, corresponding more or less closely with the amount of elevation in the region; and this excavation, as already explained, gave additional height to the bordering terraces. Many lakes were drained that had been made by the northward depression of the land, thus carrying forward the drying of the continent that was commenced with the subsiding of the flood.

In Europe, the elevation of which the terraces are testimony appears to have ended in *a second Glacial epoch*. Marks of this epoch may yet be deciphered in America. The destruction of the Elephant or Mammoth of Champlain America, and of the great Sloth-like beasts and their cotemporaries mentioned beyond, may have been a consequence of it. But the Mastodon and some other Champlain species probably survived into the later part of the Recent period.

On the coast of Maine, there are large Indian shell heaps of the common Clam (*Venus mercenaria*, the *Quahog* of the Indians) and, in some places, of the Virginia Oyster, species which are now nearly extinct on that cold-water coast. As made known by Verrill, there is a colony of living southern species in Quahog Bay, near Bath (twenty miles east of Portland), among which are *Venus mercenaria* Linn., *Modiola plicatula* Lam., *Ilyanassa obsoleta* Stimp., *Urosalpynx cinerea* Stimp., *Crepidula fornicata* Lam., *Asterias arenicola* Stimp., *Eupagurus longicarpus* Edw., and others, reminding one strongly, as Verrill says, of the coast fauna of New Haven, on Long Island Sound; and the *Venus*, *Ilyanassa*, *Modiola*, and other species occur also in Northumberland Straits, in the southern part of the Gulf of St. Lawrence. At the mouth of Damariscotta River, thirty miles east of Portland, there is the only locality of the living oyster north of Massachusetts Bay. Shells of Oysters, Clams, and Scallops (the southern *Pecten irradians* Lam.) are abundant in the deeper portions of the mud of the harbor of Portland. These species are relics of a past abundant southern population; none of the shells are found in elevated beaches; and hence the migration from south of Cape Cod took place in the Recent period. Such a migration, extending to the St. Lawrence Gulf, was not possible, unless the Labrador current had first been turned aside; and a closing of the Straits of Bellisle would have brought this about. This implies an elevation of about two hundred feet; and it may be that the one which introduced the Recent period carried the continent, to the north, to this height above the present level. Such an event would have been in harmony with the occurrence of a second Glacial epoch.

III. Recent Period in Europe and Great Britain.

The fact of a second Glacial epoch, which is still under discussion, is urged by Swiss geologists and others of Europe. The evidence of

it, which has been adduced, is found in the Glacial deposits of the Alps and of the river valleys leading from these mountains; in similar phenomena, though as yet less well understood, in Great Britain; in the occurrence in southern France of remains of Arctic and Subarctic quadrupeds, among which the Reindeer was prominent; in the occurrence, as explained beyond, of skeletons and tusks of the Elephant of the Champlain era in Siberia, on the borders of the Arctic Sea, and of whole carcasses, the meat untainted, encased in Arctic ice, proving that death invaded the region in consequence of a sudden refrigeration of climate. It is also attested by facts connected with early human history.

According to Von Morlot, the Alps, after the Glacial period, that is, at the opening of the Champlain, subsided one thousand feet; and the glacier retreated from lower Switzerland to the Alpine valleys. But afterward a second extension of the ice took place, covering again all lower Switzerland, but not the Juras, and making new deposits of lœss along the valley of the Rhine.

Lyell remarks on a parallel succession of events in Britain, and on the second epoch of cold having been coincident with a reëlevation of the land. This reëlevation probably went forward slowly, through the closing part of the Champlain period; and it may have ended in carrying the surface above the present level.

The reëlevation, before it was fully completed, cut off the Baltic again from the ocean on the north and west; for, as Erdmann shows, while on the upper terraces the shells of the Baltic coasts include the outside kind, *Yoldia Arctica*, there are lower terraces from which the open sea species are all excluded, excepting a few Baltic kinds, of which the *Mytilus* is the most common. The cutting off of the Caspian and Aral seas from the northern ocean has been referred to this epoch of elevation.

The deposits of the Recent period, after the second Glacial epoch, were made, observes Lyell, when the land stood for the most part near its present level, with the great features of the surface as they are now. The shell heaps (*Kjökken-mödding* or *Kitchen-middens*) then made, on the coasts of Danish Islands in the Baltic, and at other localities, contain no remains of the *Reindeer*, showing that the Arctic cold had receded toward its present northern limits, while those of the *Urus*, *modern Stag*, *Roedeer*, *Wild Boar*, *Dog*, *Wolf*, and other existing species are common.

On the southern side of Sardinia, at Cagliari, beds of recent shells, with bits of antique pottery, are found at heights of two hundred and thirty to three hundred and twenty-four feet above the sea, as described by Count Albert de la Marmora. There is evidence in the remains of Mammals, that Europe was connected with both Africa and Britain in some part of the Quaternary.

4. Life of the Early and Middle Quaternary.

It has been already stated that the Plants and Invertebrates (Mollusks, etc.) of the Quaternary are, with a rare exception, *living species*, while the Mammals are *nearly all extinct*. The latter are therefore the species of highest interest. They include not only brute Mammals, but also Man.

I. Brute Mammals.

1. Europe and Asia. — The Mammals or Quadrupeds of Quaternary Europe are remarkable for their great size. Caverns in Britain and Europe were the dens of gigantic Lions and Hyenas, while Pachyderms and Ruminants, equally gigantic, compared with modern species, roamed over the continent, from the Mediterranean and India to the Arctic seas. The remains are found in the earthy or stalagmitic floors of caverns; mired in ancient marshes; buried in river and lacustrine alluvium, or sea-border deposits; or frozen and cased in Arctic ice. Stalagmite (p. 75) is always forming in limestone caverns, and envelopes anything that may lie on the floor.

Fig. 946.

Canine tooth of the Cave Bear.

In Great Britain, the Champlain Mammals have been found in river-border formations, in a large number of localities; and several of these have afforded also relics of Man. The species of Mammals are with few exceptions the same that have been found also in caverns. The lœss of the Rhine and the valley formations of other parts of Europe have afforded similar facts. The European caves were mostly caves of Bears (the great *Ursus spelæus* Rosenmüller), while those of England were occupied by Hyenas (*Hyæna spelæa* Goldf.), with few bears. This Cave Hyena, al-

though of unusual size, is now regarded as of the same species with the *Hyæna crocuta* Zimm., of South Africa; and the Cave Lion, or *Felis spelæa*, as a variety of *Felis leo* Linn., or the Lion of Africa.

In a cavern at Kirkdale, one of the earliest explored, Hyena bones and teeth belonging to about three hundred individuals were mingled with remains of extinct species of Elephant or Mammoth (*Elephas primigenius*), Bear, Rhinoceros, Hippopotamus, Deer, along with the Cave Lion, the Brown Bear (*Ursus Arctos* Linn.), the Horse, Hare, etc.,— all of which then populated Britain. The Hyenas hither dragged the dead carcasses they found, and lived on the bones, and also on the bones of fellow Hyenas; and the bottom of the cave was covered with the fragments. Calcareous excrements are also abundant, quite similar to the excrements of the modern Hyena.

Kent's Hole, near Torquay, has afforded bones of the *Mammoth*, *Rhinoceros* (*R. tichorinus*), Cave Bear, Cave Lion, Cave Hyena, Irish Deer, *Machærodus latidens* Owen, besides relics of Man, in the form of flint implements; and the Brixham Cave, in the same vicinity, in addition to flint implements, bones of the Cave Bear, Brown Bear, Grizzly Bear (*U. ferox*), Elephant, Cave Hyena, Cave Lion, Wolf, Fox, Modern Horse, Reindeer, Goat, Irish Deer, Elk, modern Hare and Rabbit, Wild Boar, *Lagomys spelæus* Owen, *Aurochs* (*Bos primigenius* Boj.), etc.

Some idea has been given of Britain in the age of Reptiles (p. 485). The following, from Owen, gives a later picture of England, — England in the Middle Quaternary.

"Gigantic Elephants, of nearly twice the bulk of the largest individuals that now exist in Ceylon and Africa, roamed here in herds, if we may judge from the abundance of their remains. Two-horned Rhinoceroses, of at least two species, forced their way through the ancient forests, or wallowed in the swamps. The lakes and rivers were tenanted by Hippopotamuses, as bulky and with as formidable tusks as those of Africa. Three kinds of wild Oxen, two of which were of colossal strength, and one of these maned and villous like the Bonassus, found subsistence in the plains." There were also Deer of gigantic dimensions, wild Horses and Boars, a Wild-cat, Lynx, Leopard, a British Tiger, larger than that of Bengal, and another Carnivore, as large, of the genus *Machærodus*, which, "from the great length and sharpness of its sabre-shaped canines, sometimes eight inches long, was probably the most ferocious and destructive of its peculiarly carnivorous family." "Besides these," continues Professor Owen, "troops of Hyenas, larger than the fierce *Hyæna crocuta* Zimm. of South Africa, which they most resembled, crunched the bones of the carcasses relinquished by the nobler beasts of prey, and doubtless often themselves waged a war of extermination on the feebler quadrupeds."

There were also in Britain a savage Bear, larger than the Grizzly Bear of the Rocky Mountains, Wolves, a gigantic Beaver (*Trogontherium*), and various smaller animals, down to Bats, Moles, Rats, and Mice. The Horse (*Equus fossilis* Meyer), though of very large size, is regarded as of the same species with the modern Horse (*E. caballus*).

The more common Elephant of the region was the *Elephas primigenius*. It lived in herds over England, and extended its wanderings across the Siberian plains to the Arctic Ocean and Behring Straits, and beyond into North America; but it seems not to have gone far south of the parallel of 40°. It is stated by Woodward that over two thousand grinders were dredged up by the fishermen of the little village of Happisburgh, in the space of thirteen years; and other localities in and about England are also noted.

This ancient Elephant was over twice the weight of the largest modern species, and nearly a third taller. The body was covered with a reddish wool and long black hair. One of the tusks measured twelve and one half feet in length; it was curved nearly into a circle, though a little obliquely. The remains are exceedingly abundant at Eschscholtz Bay, near Behring Straits, where the ivory tusks of ancient generations of elephants are gathered for exportation. At the mouth of the Lena, one of these animals was found, at the beginning of this century, frozen and encased in ice. It measured sixteen feet four inches in length, to the extremity of the tail, exclusive of the tusks, and nine feet four inches in height. It retained the wool on its hide, and was so perfectly preserved that the flesh was eaten by the dogs.

The common Rhinoceros was the *R. tichorinus.* It spread from England to Siberia. A frozen specimen was found near Wilui, in Siberia, in 1772. It had a length of eleven and a half feet, and was a hairy species.

The Irish Deer (*Cervus megaceros*), was another of the gigantic species. Skeletons have been found in marl, beneath the peat of swamps, in Ireland and England, and fragments in the bone-caverns. The height, to the summit of the antlers, in the largest individuals, was 10 to 11 feet; and the span of the antlers was 10 feet, and in one case over 12 feet.

The Elephant has in all twenty-four teeth (grinders), but usually only eight at a time, two in each side of each jaw. The new teeth come up behind, and push the others forward and out; and thus there is a succession until the last has grown. Another Elephant of the era was the *E. antiquus* Falc. Both the *E. antiquus* and *E. Africanus* Cuv. have been found on Sicily. Besides the common hairy *Rhinoceros tichorinus*, the *R. hemitœchus* Falc. occurs in the British and French bone-caves. One of the Champlain oxen, the Aurochs, still lives under the protection of the Russian Czar; and the other, *Bison priscus* Ow., or Urus, was alive in the time of the Romans.

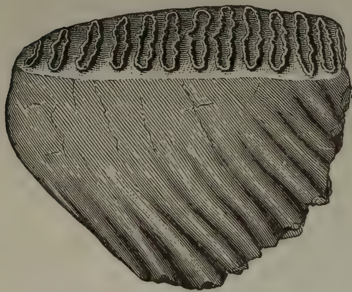
Many species of the present day were associated with the extinct kinds; as is exhibited in the list of species from Kent's Hole.

2. America. — America in the Quaternary era was inferior to Europe in the number of its Carnivores, but exhibited the gigantic feature of the life of the time in its species.

In *North America*, the mammals included an *Elephant*, *E. Americanus* Dekay, as large as the European, besides the Asiatic *E. primigenius* Blum., in the more northern latitudes; a *Mastodon*, *M. Americanus* Cuv., of still greater magnitude; *Horses* much larger than the modern; species of *Ox*, *Bison*, *Tapir*, gigantic *Beavers*, species of *Dicotyles* (related to the Mexican Peccary); also animals of the Sloth tribe, of the genera *Megatherium*, *Mylodon* and *Megalonyx*, of great size, compared with those now living. Among Carnivores, there were

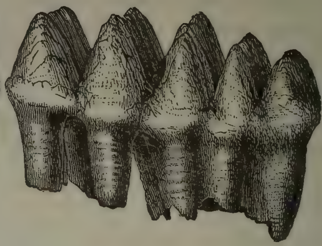
a *Bear*, a *Lion*, and a *Raccoon;* and these were probably not cavern species; none of the many caverns of the country appear to have been the haunts of Carnivores.

Fig. 947.



Tooth of Elephas Americanus (×¼).

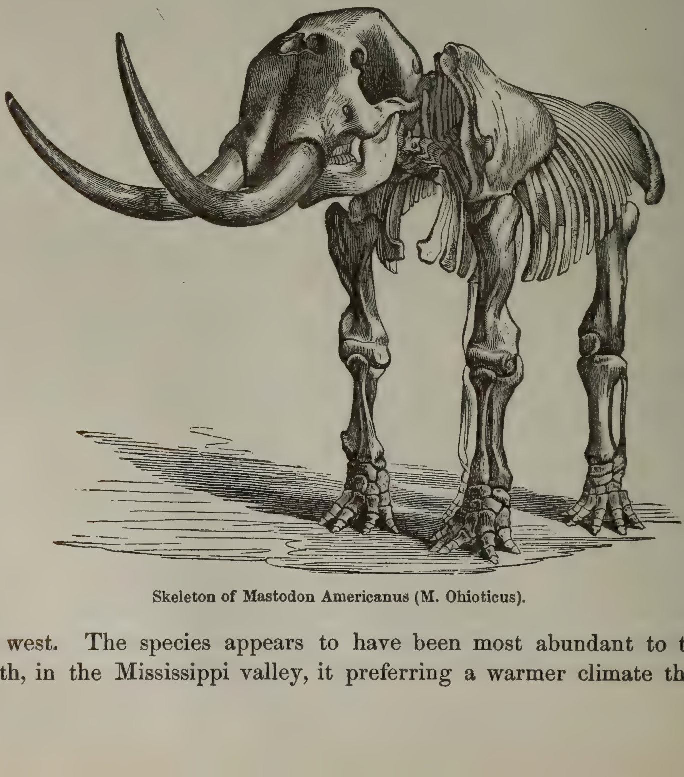
Fig. 948.



Tooth of Mastodon Americanus (×¼).

The American Elephant ranged from Georgia, Texas, and Mexico on the south to Canada on the north, and to Oregon and California on

Fig. 949.



Skeleton of Mastodon Americanus (M. Ohioticus).

the west. The species appears to have been most abundant to the south, in the Mississippi valley, it preferring a warmer climate than

the *E. primigenius*. Fig. 947 represents one of the teeth (reduced to one-fourth lineally), found in the State of Ohio.

The teeth differ from those of the *E. primigenius*, in having the enamel plates less crowded.

Mastodon remains (Fig. 949) are met with most abundantly over the northern half of the United States, though occurring also in the Carolinas, Mississippi, Arkansas, and Texas. They are found also in Canada and Nova Scotia. The best skeletons have been dug out of marshes, in which the animals had become mired. Three perfect skeletons have been obtained from the fresh-water marshes of Orange County, N. Y.; another from near Cohoes Falls, on the Mohawk; another in Indiana; one from a morass in New Jersey; another on the banks of the Missouri. In New England, a few bones have been found near New Britain and Cheshire, Connecticut. The best of the skeletons is that set up by Dr. Warren, at Boston: it was obtained from a marsh near Newburgh. Its height is 11 feet; the length to the base of the tail, 17 feet; the tusks 12 feet long, — $2\frac{1}{4}$ feet being inserted in the sockets. When alive, the height must have been 12 or 13 feet, and the length, adding 7 feet for the tusks, 24 or 25 feet. Remains of the undigested food were found between his ribs, showing that he lived in part on spruce and fir trees. Fig. 949, from Owen's "British Mammals," represents the skeleton of this species in the British Museum; and Fig. 948, one of the teeth, one fourth the natural size.

Castoroides Ohioensis Foster was a great Rodent related to the Beaver (*Castor Canadensis* Kuhl). The Beaver is an animal about three feet long, exclusive of the tail; and the *Castoroides* was almost or quite five feet. Its bones have been found in the States of New York, Ohio, Mississippi (near Natchez), etc.

Bison latifrons L. was a Bison or Buffalo, much larger than the existing Buffalo, which lived in the Mississippi and Ohio valleys, and over the Southern States to Texas. There were also species related to the Musk-ox, *Ovibos bombifrons* L. and *O. cavifrons* L.

A Stag, *Cervus Americanus* Harlan, whose bones were found near Natchez, equalled, if they did not exceed in size, the Irish Deer. A Horse from the same locality was also gigantic, — a fit cotemporary, as Leidy observes, of the Mastodon and Elephant.

The Lion, *Felis atrox* L., was about as large as that of Britain. Only a single jawbone of it has been found at the Natchez bone-locality, where occur remains of species of Bear (*Ursus amplidens* L.), Horse, Elephant, *Mastodon*, *Castoroides*, *Megalonyx*, and *Mylodon*.

A vertical opening in the limestone strata at Port Kennedy, eastern Pennsylvania, described by C. M. Wheatley, has afforded remains of a large number of species of extinct Mammals, the animals having fallen into it as into a trap. As identified by Cope, the bones belong to thirty-four species and seventy-two individuals, and include two Tapirs (*T. Americanus* L. and *T. Haysii* L.), a Bear (*Ursus pristinus* L.), a *Felis*, an *Ox*, a *Horse*, the American *Mastodon*, several species of *Megalonyx*, one of *Mylodon* (*M. Harlani* Owen (?)), several Rodents and a Bat. Cope observes that eleven were warm-climate species, and three North American Arctic.

A cave in Wythe County, Va., and another near Galena, Ill., contain some extinct species, along with others that are living. (Cope, Proc. Am. Phil. Soc., xi. 171).

In a cave near Carlisle, Pennsylvania, Baird found bones of all the species of Mam-

mals of the State, besides one or two other species not now Pennsylvanian, but known in regions not far remote: as a general rule, the bones of the cave appear to indicate that the size of the species exceeded that at the present time.

In North America, some of the Mammals appear to belong to the Recent or Terrace period. Among these, according to Holmes and Leidy, there were probably the modern Horse, or one similar to the common species, the Gray Rabbit and the Tapir; and to these Dr. Holmes adds the Bison, Peccary, Beaver, Musk-rat, Elk, Deer, Raccoon, Opossum, Hog, Sheep, Dog, and Ox. The species, however, have not in all cases been identified with certainty; and it is not settled that the commingling of bones is not of more modern origin. In western Canada, Chapman has found remains of the modern Beaver, Musk-rat, Elk (*Cervus elaphus*), and Moose, in stratified gravel which contained also bones of the Mammoth and Mastodon.

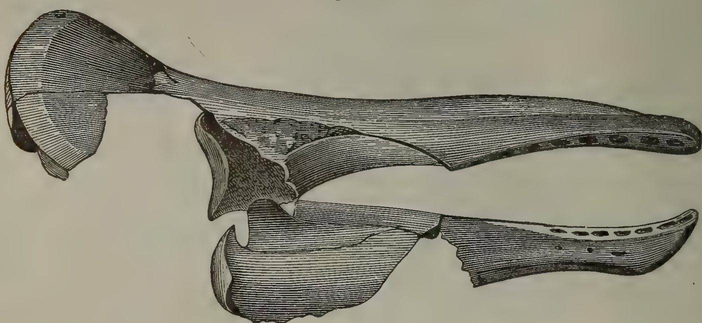
The Quaternary deposits have afforded Marsh remains of the Birds, *Meleagris altus* Mh., and *M. celer* Mh. (Turkeys), from New Jersey; *Grus proavus* Mh., ibid.; and *Catarractes affinis* Mh., from Maine.

Remains of the *Reindeer* have been found on Racket River and at Sing Sing, in New York, near Vincenttown, in New Jersey, and at Big-bone Lick, in Kentucky.

The animals of the Sloth tribe are South American in type. They are at the present time mostly confined to South America, as they were also in the Quaternary.

The Cetacean, or *Whale*, *Beluga Vermontana* Thompson, whose remains were found on the borders of Lake Champlain, is supposed to

Fig. 950.



Beluga Vermontana ($\times \frac{1}{6}$).

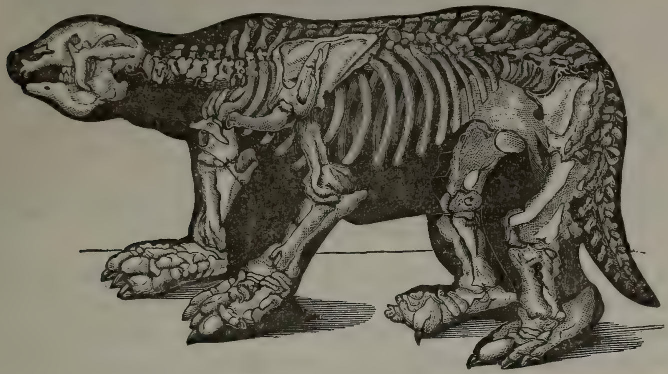
have been about fourteen feet in length. Fig. 950 represents the bones of the head, reduced to one-sixth the natural size. The species closely resembles the *B. leucas* Gray, or small northern White Whale.

3. South America. — In South America, over one hundred species of extinct Quaternary quadrupeds have been made out. The bones occur in great numbers, over the prairies or pampas of La Plata, and in the caverns of Brazil; and they include some thirty species of Rodents (*Squirrels*, *Beavers*, etc.), species of *Horse*, *Tapir*, *Lama*, *Stag;* a *Mastodon* different from the North American; *Wolves*, and half a dozen Panther-like beasts, which occupied the caverns of Brazil; and, among Edentates, *Ant-eaters*, twelve or fourteen species related

m tribe to the *Megatherium* (Sloth tribe), and a dozen or more related to the *Armadillo*. They number more species than now exist in that part of the continent, and include far larger animals.

The Edentates — including the Sloth, Armadillo, and allied species — were the most remarkable. The animals of this order are stupid in aspect, and lazy in movement and attitude.

Fig. 951.



Megatherium Cuvieri ($\times\frac{1}{75}$).

The *Megatherium* (*M. Cuvieri* Desmarest, Fig. 951) exceeded in size the largest Rhinoceros. The length of one of the skeletons is eighteen feet. Its massy limbs were more like columns for support than like organs of motion. The femur was three times as thick as an Elephant's; the clumsy tibia and fibula were soldered together; the huge tail was like another hind leg, making a tripod to support the heavy carcass when the animal raised and wielded its great arms; and the hands terminating the arms were about a yard long, and ended in long claws. The teeth had a grinding surface of triangular ridges, well fitted for powerful mastication.

A North American *Megatherium* (*M. mirabile* L.) has been found in Georgia, at Skiddaway Island, and in South Carolina.

Megalonyx is another genus of these large Sloth-like animals. Remains of species occur over the Pampas, to the Straits of Magellan; but the first species known was found in Virginia, in Greenbrier County, and was named *Megalonyx* by Jefferson, in allusion to its large claws (Fig. 952). Its bones have also been found at Big-bone Lick and elsewhere.

Mylodon is a third genus; and three species have been described, — two from South and one from North America. The skeleton of one, *M. robustus* Owen, is eleven feet in length; and the animal was therefore much larger than the western Buffalo. The

North American, *M. Harlani*, has been found both east and west of the Mississippi, and in Oregon.

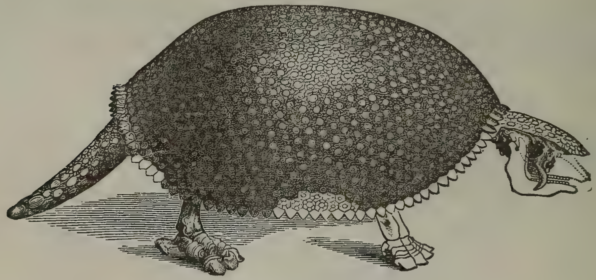
Fig. 952.

Claw of Megalonyx Jeffersonii, nat. size.

A fourth allied genus is *Scelidotherium*, of which seven South American species have been made out, — one as large as the *Megalonyx*.

Of the Armadillo (or *Dasypus*) group, the genus *Glyptodon* (Fig. 953) contained several gigantic species. These animals had a shell something like that of a Turtle. In the *G. clavipes* Owen, the length of the shell, measuring along the curve, was five feet, and the total

Fig. 953.



Glyptodon clavipes ($\times \frac{1}{30}$).

length of the animal, to the extremity of the tail, nine feet. The genus *Chlamydotherium* included other mail-clad species, one of which was as large as a Rhinoceros; and the genus *Pachytherium*, others, of the size of an Ox.

Such were the characteristic animals of Quaternary South America. The largest Edentates of the existing period are but three or four feet in length. The *Megatherium* probably exceeded more than *one hundred fold* the bulk of any living Edentate.

5. Australia. — In Australia, the living species are almost exclusively Marsupials. They were Marsupials also in the Quaternary, but

of different species; and, as on the other continents, the moderns are dwarfs by the side of the ancient tribes. The Quaternary *Diprotodon* was as large as a Hippopotamus, and somewhat similar in habits, the skull alone being a yard long; and the *Nototherium Mitchelli* Ow., an herbivorous species, was as large as a bullock.

The oldest Quaternary remains, referred to the *early part of the Glacial Period* by Dawkins, are those of the Cromer Forest-bed (p. 559). They include, besides the Cave Bear, *Elephas primigenius*, the Irish Deer, *Trogontherium Cuvieri* Fischer; and several modern species, as the Beaver, Wolf, Fox, Stag, Aurochs, Mole, Wild Boar, Horse; also the European Pliocene speoies, *Ursus Arvernensis*, *Cervus Polignacus* Robert, *Hippopotamus major* Cuv., *Rhinoceros Etruscus*, *R. megarhinus*, *Elephas meridionalis*, with *E. antiquus*, and without any remains of Man. The *Machærodus latidens*, found in Kent's Hole, is a representative of an eminently Miocene and Pliocene genus.

The characteristic species of the *Champlain period*, are Man, the Cave Hyena, Cave Bear, Cave Lion, Brown and Grizzly Bears, Fox, Wolf, Cat, *Elephas primigenius* and *E. antiquus*, *Rhinoceros tichorhinus* Cuv., *R. hemitæchus* Falc., *R. megarhinus* Christol, *Hippopotamus major* Cuvier, Wild Boar, Aurochs, Urus, Stag, Goat, *Cervus Browni*, Musk-ox, Beaver, Horse, etc., with few remains of the Reindeer. Those of the Reindeer era are the same species nearly, with very abundant remains of the Reindeer, Aurochs, and Urus, and fewer of the extinct cave Carnivores, with also the Lemming, and some other northern species. (See further, pages 576, 577.)

6. Conclusions. — (1.) *General features of the Life of the Early and Middle Quaternary.* — Viewing the globe as a whole, in this Quaternary era, we observe, —

1. The gigantic size as well as large numbers of the species, — the Elephants, Lions, Bears, and Hyenas of the Orient far larger than the modern kinds; so also the Horse, Elephant, Mastodon, Beavers, and Lion of North America; the Megatheria and other Edentates of South America; the Diprotodon and other Marsupials of Australia.

2. The characteristic species of each continent were mainly of the same type that now characterizes it. Both in the Quaternary and at the present time, the Orient is strikingly the continent of Carnivores; North America, of Herbivores; South America, of Edentates; Australia, of Marsupials.

7. Evidence, from the Life, with regard to the Climate and the Migrations of the Champlain Period. — The Quaternary species which have been mentioned, with a very few exceptions noted below, must have required a climate ranging between warm-temperate on one side, and extreme cold-temperate on the other; and this range belonged to the wide region from middle Europe and Britain to northern Siberia, where herds of Elephants, hairy Rhinoceroses, and other Mammals found abundant vegetation for food, and a good living-place. If northern Siberia had then the mean temperature now found in southern Scandinavia, or 40° F., instead of its present 5° F. to 10° F., central Europe would necessarily have been within the warm-temperate zone. The cause of such a climate is found in the

extensive submergence of northern lands, giving an unusual sweep northward to the Gulf Stream and the corresponding warm current of the Pacific. Perhaps in the earlier part of the period, before the glacier had disappeared from northern Europe and America, Arctic Asia was still very cold; but, long before its close, the Elephants had taken full possession, as the vast abundance of their remains attests.

But, while these and other Champlain species evidently culminated during that period, it is probable that they were in existence south of Glacial latitudes before the Glacial period closed. For, if the migrations of the species from Europe to southern England had not taken place in the Glacial era, that is, during the era of continental elevation for the higher latitudes, the animals would not have been there in Champlain time, since, in this period, — an era of continental depression, — Britain was for the most part 200 to 1,500 feet below its present level; and Europe also was at less elevation than now, and hence the British Channel had much greater width.

The rarity of remains of Quaternary Mammals in Scotland and Ireland, in contrast with England and Wales, where they have been found in over one hundred and fifty localities, has been attributed by Dawkins to the lingering of the ice longer about the Scotch and Irish mountains.

8. Evidence, from the Life, with regard to the Conditions of the Reindeer Era, or opening part of the Recent Period. — The cold of the second Glacial epoch, — the Reindeer era of Lartet, — appears to have brought destruction among the northern tribes of Europe and Asia, and, at the same time, to have driven southward the more active of survivors, or those which had the best chance for escape. The encasing in ice of huge Elephants, and the perfect preservation of the flesh, shows that the cold finally became *suddenly* extreme, as of a single winter's night, and knew no relenting afterward. The existence of remains of the Reindeer in southern France, in vast quantities, of the Marmot, also a northern species, and of the Ibex and Chamois, now Alpine species, is attributed by Lartet to the forced migration thus occasioned. In the caves of Perigord (Dordogne, etc.), the bones of the Reindeer, far the most abundant kind, lie along with those of the Cave Hyena, Cave Bear, Cave Lion, Elephant, Rhinoceros, as well as Horse and Aurochs.

Lartet says that, in the Drift or valley-gravels, the Elephant, Rhinoceros, Horse, and Ox are the predominant species, and the Reindeer appears sparingly; while, in the Dordogne Caves, the Reindeer predominates, being associated in large numbers with the Horse and Aurochs, and exceptionally with remains of the Elephant, Hyena, etc. With the Mammals of the Reindeer era, in southern France,

there are also great numbers of Grouse and the Snowy Owl, species which have since returned to northern Europe.

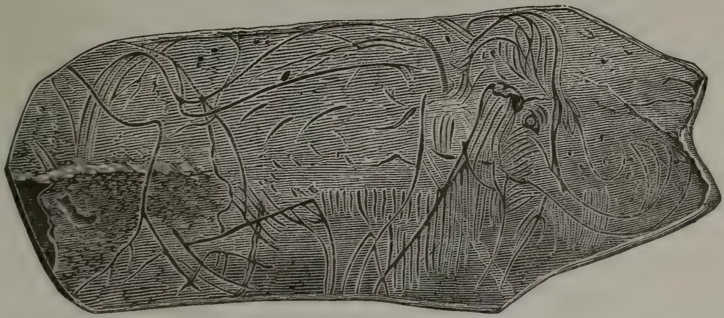
The elevation of the land during the second Glacial epoch, or Reindeer era, probably made again a dry land connection between Britain and the continent, permitting of migration of the later species. The Reindeer was living in Scotland, until near the end of the twelfth century.

The absence of remains of the Reindeer and other Subarctic species from Spain and Italy, and the southern character of the Champlain fauna, are evidence that the cold of the second Glacial period did not extend beyond the Alps and Pyrenees, over southern Europe.[1] At the same time, the presence of abundant remains of the Reindeer in Belgian deposits of this era, without bones of the extinct Mammals may be evidence that the cold of Belgium was severe enough to have driven off the old warm-climate quadrupeds. An isothermal chart shows that England would have had a warmer climate than Belgium.

II. Man.

1. Ancient Human relics. — The relics of Man, through which his geological history has been deciphered, are: (1) buried human bones; (2) stone arrow-heads, lance-heads, hatchets, pestles, etc.; (3) flint chips, made in the shaping of stone implements; (4) arrow-heads or harpoon-heads, and other implements, made of horns and bones of

Fig. 954.



Elephas primigenius; engraved on ivory ($\times\frac{2}{5}$).

the Reindeer and other species; (5) bored or notched bones, teeth, or shells; (6) cut or carved wood; (7) bone, horn, ivory, or stone, graven with figures of existing animals, or cut into their shapes, — one example of which, found by Lartet, in the bone cave of La

[1] On the Quaternary Fauna of Britain and Europe, see papers by W. Boyd Dawkins, in Quart. Journ. Geol. Soc., xxv. 192, 1869; xxviii. 410, 1872.

Madelaine, Perigord, and representing the old Hairy Elephant, is here given; (8) marrow-bones broken longitudinally, in order to get out the marrow for food; (9) fragments of charcoal, and other marks of fire for warming or cooking; (10) fragments of pottery. Relics of the above kinds occur in the deposits of the "Stone Age."

In later deposits, occur bronze implements, without iron — marking a "Bronze Age;" and, still later, iron implements, or those of the "Iron Age;" and here occur, as fossils, coins, inscribed tablets of stone, buried cities, such as Nineveh and Pompeii, etc.

The "Stone Age," here referred to, is properly the Stone Age of European or Oriental history. The Stone Age, in North America, or a large part of it, continued in full force till within two centuries since.

The age has been divided by Lartet into —

1. The PALEOLITHIC era; the Mammoth period of Dupont; the Champlain period.

2. The REINDEER era, or second Glacial epoch; or commencement of the Recent period.

3. The NEOLITHIC era; a section of the Recent period, following the Reindeer era, and commencing the MODERN era.

The terms *Paleolithic* and *Neolithic* were proposed by Lubbock, who recognizes in his work only these two divisions in the "age of stone."

The principal facts with regard to human relics are these: —

1. Stone implements occur intimately associated with the remains of the Cave Bear, Cave Hyena, Cave Lion, the old Elephant and Rhinoceros and other extinct species, with some remains of the Reindeer and other living Mammals, in deposits of the later if not the earlier part of the Champlain period, — the *Paleolithic* era, — proving the existence of Man at that time.

2. Similar implements, along with others of horn and bone, and drawings of animals, and other markings, occur in Southern France, as well as more to the north, in caves and river-border deposits, along with great numbers of bones of the Reindeer, and a number of other northern species, now existing, and also with the remains of the extinct Urus, Elephant, Cave Bear, Cave Hyena, Cave Lion, etc., and also the now living Aurochs, Ibex, Elk, etc., the deposits being those of the *Reindeer era*, and the Reindeer a colonist there from the north, during this second Glacial era. And, with these relics, human bones and even complete skeletons have been found: the marrow bones of the Reindeer and Aurochs so split as to show that they were broken by Man for the marrow; and charcoal and other relics of fires, probably used both for cooking and for warmth; for the weather must have been sometimes, if not generally, cold.

3. The skeletons, supposed to be *Paleolithic*, of Southern Europe,

are in part those of tall men. One of them, that of the cave of Mentone in the Mediterranean (just east of Nice,) according to its describer, Mr. Rivière, was that of a man six feet high, with a rather long but large head, high and well made forehead, and very large facial angle — 85°. The frontispiece, from a photograph published by Rivière, represents the skeleton as it lay, partly uncovered from the stalagmite, with Mediterranean shells and flint implements and chippings lying around, and a chaplet of stag's canines across his skull. It has been regarded as one of the oldest human skeletons yet found. A similar skeleton was obtained from the cave of Cro-Magnon, in Perigord, France, whose height was five feet eleven inches, and another at Grenelle, about five feet ten inches. These are referred to the Reindeer era; and the Mentone skeleton may be of the same, instead of Paleolithic.

The human remains of caverns on the Lesse valley, in the vicinity of Liége, Belgium, first discovered by Schmerling in 1833–1834, are regarded as unquestionably *Paleolithic*. They belonged to less tall men; the cranium was high and short, and of good Caucasian type, though of medium capacity; "a fair average human skull," observes Huxley. But one Belgian jaw-bone from the cave of the Naulette, recently found by Dupont, has several marks of inferiority, for example, remarkable thickness and small height; the molar teeth increasing in size backward, the posterior or "wisdom-tooth" being the largest (besides having five roots), while the reverse is the case in civilized man; the prominence of the chin wanting. Fragments of crania and of some other bones were found with the jaw-bone.

A skeleton of low grade was found in 1857 in the small Neanderthal Cave, near Düsseldorf, where Lyell thinks it may have been washed in. The mud in which it lay contained no Quaternary remains as evidence of its antiquity. Lyell states that the tusk of a Bear, whether ancient or not is unknown, was found in the mud of a branch of the cave, on the same level with the skeleton, and that, at the bottom of the lœss of the region, Huxley found bones of the extinct Rhinoceros. Both Huxley and Lyell "think it probable" that it is of the same age with the remains of the Liége caverns found by Schmerling; and Lyell says that "its position lends no countenance whatever to the supposition of its being more ancient." The forehead is low, and the head long; the brow-ridges very prominent, a little ape-like; but the cranial capacity was about seventy-five cubic inches, or "nearly on a level with the mean between the two human extremes" and "in no sense" adds Huxley "can the Neanderthal bones be regarded as the remains of a human being intermediate between Man and the Apes." The bones of the arm and thigh have the ordinary proportions in Man, though very stout.

The human crania of the caves of Furfooz in Belgium, of the Reindeer era, are described as intermediate between the broad and long types, and as "Mongoloid," approaching those of the Finns and Laplanders. The height of the men was not over four and a half feet, and thus they were like existing Man of Northern Europe; and it would seem as if Laplanders had been driven south by the cold, as well as Reindeers. The habits of the people, according to Dupont, were like those of the Esquimaux.

4. In Denmark and elsewhere occur polished stone implements, with broken pottery, with no remains of either the extinct Quaternary Mammals or the Reindeer, but with bones of existing quadrupeds, and among them those of the domesticated Dog. These belong to the *Neolithic* era. The Neolithic human remains of Denmark indicate the same small, round-headed race, Laplander-like, that were found in the Reindeer caves of Belgium.

5. In the same era, or perhaps a little later, in the Neolithic era, existed the oldest of the lake-dwellings of Switzerland (dwellings in lakes, on piles, such as Herodotus described over two thousand years since). They have afforded stone-implements and pottery, with remains of Goats, Sheep, the Ox, as well as the Dog, but not the Reindeer or any extinct species; also, of Wheat and Barley; also a human skull, neither very long nor very short, but, according to Rutimeyer, much like those of the modern Swiss. These Neolithic structures occur mainly about the eastern lakes, Constance and Zurich, while those of the "Bronze Age" are found in the western lakes.

Lake-dwellings or "stockaded islands," called *Crannoges*, have been found in peat-bogs in the British Isles, and especially in Ireland. They belong to the bronze and stone ages, affording remains of various living species of quadrupeds, with stone implements in some of them.

1. *Paleolithic.* — The river-border deposits of Amiens and Abbeville, in the valley of the Somme (about seventy-five miles north of Paris), are here referred by Lartet. They contain, in the lower parts of the deposits, flint implements, along with the bones of the old *Elephant*, *Rhinoceros*, *Hippopotamus*, *Hyena*, *Horse*, and other species.

Various deposits in caverns and elsewhere, in Great Britain, may be as old — as those of Bedford, and at Hoxne in Suffolk, Wookey Hole near Wells, the Gower Caves in South Wales, etc., where the occurrence of flint implements proves Man to have been a cotemporary of the Hyena that inhabited the caves. In Kent's Hole, near Torquay, which may be of later occupation, the flint arrowheads, knives, and flakes were found at the bottom of the cave-deposit, as well as above, so that there was no ground for making Man a successor in occupancy to the Bear, Cave Lion, and other wild beasts of the country. Among the bones occurred remains of the Lion, *Machærodus latidens.*

In a cave near Settle, Yorkshire, a human fibula, much like that of the skeleton of Mentone, has been found, along with remains of the extinct Elephant, Bear, Hyena, Rhinoceros, and also the Bison and Elk; and at the mouth of the cave there is a bed of stiff glacial clay, with scratched bowlders.

The evidence appears to place Man in Britain and Europe at least as early as the Alluvian part of the warm Champlain era, and probably earlier. The jawbone of the

Naulette cave in Belgium, described above, pronounced incontestably *Paleolithic*, occurred with remains of the Elephant, Rhinoceros, Horse, Wild Boar, Chamois, Goat, Reindeer, Stag, Marmot, Squirrel, Hare, Water-rat, Wolf, Brown Bear, and others, and with those of the Cave Hyena, the cave having been a Hyena cavern, and many of the other animals its prey, or that of Man.

2. *The Reindeer Era.* — The extinct and other Mammals of southern France are mentioned on page 572. With the exception of the skeleton of Mentone, they have been referred to the Reindeer era. With them occur stone implements, like those of Amiens, only somewhat better fashioned. Among the drawings on bones, of different animals, are those of Horses and one of the Hairy Elephant (p. 573), proving that these species were cotemporaries of the draftsman. In one of the Gower caves in South Wales, called Bosco's Den, no less than one thousand antlers of the Reindeer were taken out, mostly shed horns; and Lyell says they had probably been washed into the cavity.

In the cave of Cro-Magnon, near Les Eyzies, bones were obtained belonging to three of the Périgord human cave-dwellers. They were of the tall race mentioned above; the cranium of one gave for its capacity 97 cubic inches, far above that of average Man. Neither the jaws nor the cheek bones were projecting: the tibia was much flattened (platycnemic).

The skeleton found in 1872, in the cave near Mentone, was associated with remains of the same extinct Mammals, the old *Cave Lion, Cave Bear, Cave Hyena*, a *Rhinoceros*, besides the *Wolf, Hedgehog, Aurochs, Elk, Stag, Deer*, etc.; but there were no *Reindeer*, showing that the remains were either Paleolithic, as held by Lyell, or else they were of the Reindeer era, and the place too warm for this northern species. The height of this extraordinarily tall man is mentioned above. The length of the radius (principal bone of the forearm), compared with the humerus as 100, was 76·9, that of the negro being 79·4, and that of the typical European 73·6. All the above species were found in the bed of stalagmite, six inches thick, above and below the skeleton. The shells buried in the same stalagmite are *Cardium tuberculatum* Linn., *Pecten Jacobæus* Lam., *Pecten maximus* Lam., *Pectunculus glycimeris, Mytilus edulis* Linn., all Mediterranean species; and some of them had been perforated by Man. Thus the ancient skeleton has around it the implements, weapons, and ornaments of the man who was once its owner. Eight feet above the skeleton, the stalagmite afforded remains of the *Rhinoceros tichorinus*, and all of the species above enumerated, excepting the Wolf, Fox, Weasel, Wild Boar, etc., and some other existing kinds.

Another specimen, found in the Drift at Clichy, was similar to the above in many points, even to the peculiar platycnemic tibia; and the latter feature belongs also to a Gibraltar specimen.

The earliest observations in Southern France were made in 1828 and 1829 by Tournal and Christol (Lyell). In the department of Aude, Southern France, in 1828, Tournal found, in the Bize Cavern, human bones, associated with remains of species of quadrupeds, including the Reindeer and Aurochs; and Christol, at the same time, observed similar facts in a cave near Nismes, bones of the Hyena and Rhinoceros being present, and also fragments of rude pottery.

3. *Neolithic Era, or Early part of the Recent Period.* — The shell-heaps (Kjökkenmödding or Kitchenmiddens) of the Danish Isles in the Baltic, some of which are ten feet high, one thousand feet long, and two hundred feet wide, are prominent among the localities of Neolithic man. Other remains of the era occur in the lower part of the Danish peat. Log canoes, found in the peat of the region, are supposed to have been used by the men the refuse of whose sea-food makes the shell heaps. (These heaps are much like those made by American Indians near sea-shores.) The shells of the shell heaps are mostly larger than those of the same species now on the Danish shores.

4. *Remains in America.* — A fragment of a human cranium was reported in 1857, by C. F. Winslow, as having been taken from the auriferous gravel of Table Mountain, in California, where this gravel underlies an extensive bed of lava (the lava being the table-like top of

the mountain.) Bones of the Mastodon and Elephant were obtained from the upper drift of the same vicinity.

Prof. J. D. Whitney has described a skull, from Calaveras County, which was found, according to the owner of the mining claim, at a depth of 130 feet from the surface, underneath the lava-bed. Doubts of its authenticity have been expressed by others who have examined the evidence; but Whitney, in his latest publication on the subject (On the Auriferous Gravels of the Sierra Nevada, 1879), refers to corroborating testimony, and gives it full credit. Whitney also mentions the discovery of flint implements in the Auriferous gravel in other parts of California. The fossil plants of the gravels are referred to the Pliocene (or partly Miocene) by Lesquereux. The few Mammalian remains include the Champlain *Mastodon* and *Elephant*, but, in some places, Pliocene species. The skull, according to Prof. Jeffries Wyman, resembles that of a modern Indian, especially the Esquimaux, but has a more prominent forehead and a larger chamber within. Flint implements have been described by C. C. Abbott from stratified drift, probably of the Champlain period, near Trenton, N. J., and by C. M. Wallace, from similar deposits near Richmond, Va.

Dr. Wyman states, respecting the remains from shell-heaps in Florida, that they have the characteristics of the ordinary Indian; the tibiæ were flattened (platycnemic), but this is common among the American Indians, as well as in the prehistoric remains of Europe. In Brazil, human remains were found many years since, by Lund, in caverns, along with extinct Quaternary Mammals; and Clausen has reported the occurrence of pottery in a bed of stalagmite containing these Mammals.

2. Man at the head of the System of Life. — In the appearance of Man, the system of life, in progress through the ages, reached its completion, and the animal structure its highest perfection. Another *higher* species is not within the range of our conceptions. For the Vertebrate type, which began during the Paleozoic in the prone or horizontal Fish, became erect in Man, and thus completed, as Agassiz has observed, the possible changes in the series, to its last term. An erect body and an erect forehead admit of no step beyond.

But, besides this, Man's whole structure declares his intellectual and spiritual nature. His fore-limbs are not organs of locomotion, as they are in *all* other Mammals; they have passed from the *locomotive* to the *cephalic* series, being made to subserve the purposes of the head; and this transfer is in accordance with a grand law in nature, which is at the basis of grade and development. The cephalization of the animal has been the goal in all progress; and in Man we mark its highest possible triumph.

Man was the first being that was not finished on reaching adult growth, but was provided with powers for indefinite expansion, a will

for a life of work, and boundless aspirations to lead to endless improvement. He was the first being capable of an intelligent survey of nature, and comprehension of her laws; the first capable of augmenting his strength by bending nature to his service, rendering thereby a weak body stronger than all possible animal force; the first capable of deriving happiness from truth and goodness; of apprehending eternal right; of reaching toward a knowledge of self and of God; the first, therefore, capable of conscious obedience or disobedience of a moral law, and the first subject to debasement through his appetites and a moral nature.

There is, hence, in Man, a spiritual element, in which the brute has no share. His power of indefinite progress, his thoughts and desires that look onward even beyond time, his recognition of spiritual existence and of a Divinity above, all evince a nature that partakes of the infinite and divine. Man is linked to the *past* through the system of *life*, of which he is the last, the completing, creation. But, unlike other species of that closing system of the *past* (significantly the *Zoic* era of geological history), he, through his *spiritual* nature, is far more intimately connected with the opening *future*.

5. Modern Era.

1. Modern relics of Man. — While the animal system is not now working onward to a loftier limit, except so far as there is improvement in the culminant species, Man, all other geological work goes on as in past times. Seas, rivers, winds, and the other agencies of change are at their old labors.

The following figures exemplify to the eye some of the relics of the times, by way of contrast with those of the beginning of geological progress. Fig. 955 represents a human skeleton, from a shell limestone of modern origin and now in progress, on the island of Guadaloupe. The specimen is in the Museum at Paris. The British Museum contains another from the same region, but wanting the head, which is in the collection of the Medical College at Charleston in South Carolina. They are the remains of Caribs, who were killed in a fight with a neighboring tribe, about two centuries since. Fig. 956 represents another fossil specimen, of the age of Man, — a ferruginous conglomerate, containing silver coins of the reign of Edward I. and some others, found at Tutbury, England. It was obtained at a depth of ten feet below the bed of the river Dove.

2. Extinction of species in Modern times. — Species are becoming extinct, as heretofore, but partly through the new agency, the pressure of civilization.

Among the species recently exterminated, there are the *Moa* (*Di-*

nornis) and other birds of New Zealand, the *Dodo* and some of its associates on Mauritius and the adjoining islands in the Indian Ocean;

Fig. 955.

Human skeleton, from Guadaloupe.

Fig. 956.

Conglomerate, containing coins.

the *Æpyornis* of Madagascar. The species are of the half-fledged kind, like the Ostrich. Fig. 957 (copied from Strickland's "Dodo and its Kindred") is from a painting at Vienna, made by Roland Savery in 1628.

The *Dodo* was a large, clumsy bird, some fifty pounds in weight, with loose, downy plumage, and wings no more perfect than those of a young chicken. The Dutch navigators found it in great numbers, in the seventeenth century. But, after the possession of the island by the French, in 1712, nothing more is heard of the Dodo; a head, two feet and a cranium are all that is left, except some pictures in the works of the Dutch voyagers.

The *Solitaire* is another exterminated bird, of the same island.

The *Moa* (*Dinornis giganteus* Owen), of New Zealand, exceeded the Ostrich in size, being ten to twelve feet in height. The tibia (drumstick) of the bird was thirty to thirty-two inches in length; and the eggs so large that "a hat would make a good egg-cup for them." The bones were found along with charred wood, showing that the birds had been killed and eaten by the natives. The name Dinornis is from δεινός, *terrible*, and ὄρνις, *bird*.

Besides the *Dinornis giganteus*, remains of other extinct species of the genus have been found; also extinct species of *Palapteryx* and *Notornis*. *Palapteryx* is related to *Apteryx*; and both *Apteryx* and *Notornis* have living species.

On *Madagascar*, other species of this family of gigantic birds formerly existed. Three species have been made out of the genus *Æpyornis*. From the bones of the leg, one is supposed to have been at least twelve feet in height. The egg was thirteen and a half inches in its longest diameter.

The Great Auk of the North Sea (*Alca impennis* Linn.) is reported to be an extinct bird, by Professor Steenstrup. The last known to have been seen were two taken near Iceland, in 1844. The bones occur in great numbers, on the shores of Iceland, Greenland and Denmark, showing that it was once a common bird; and its remains have been found also on the coasts of Labrador, Maine, and eastern Massachusetts. They

occur in the shell-heaps of Maine, Wyman having found seven specimens of the humerus, besides other bones. With these are bones of other species, but of none that are extinct, and also fragments of rude pottery, and some bone-implements.

A species of Manatee, *Rytina Stelleri* Cuv., known in the last century on the Arctic shores of Siberia, is supposed to be now extinct.

Fig. 957.

Dodo, with the Solitaire in the background.

The Aurochs (*Bison priscus*) of Europe, one of the cotemporaries of the old Elephant (*E. primigenius*), would have long since been exterminated from Europe, but for the protection of Man. Though once abundant, it is now confined on that continent to the imperial forests of Lithuania, belonging to the Russian Czar. It is said to exist also in

the Caucasus. The now extinct *Bos primigenius* is supposed to be the same with the *Urus* (Ure-Ox, or *Bos Urus*, described by Cæsar in his Commentaries, and stated to abound in the Gallic forests,) and is a distinct species from the Aurochs, with which it has been confounded. It is said to have continued in Switzerland into the sixteenth century.

The American Buffalo (*Bos Americanus* Gm.) formerly covered the eastern part of the continent, to the Atlantic, and extended south into Florida, Texas, and Mexico; but now it is never seen east of the Missouri, excepting its northern portion; and its main range is between the Upper Missouri and the Rocky Mountains, and from northern Texas and New Mexico to Great Martin Lake in latitude 64° N. (Baird.)

The spread of the farms and settlements of civilization is gradually limiting, all over the globe, the range of the wild animals, especially those of large size, and must end in the extermination of many now existing.

Dr. Asa Gray says that the giant *Sequoia* or Redwood of California is sure to become extinct as a native plant, and adds: "Few and evil are the days of all the forest likely to be, while Man, both barbarian and civilized, torments them with fires, fatal at once to seedlings, and at length to the aged also."

3. Changes of level in the Earth's surface. — Although the earth has now reached a state of comparative stability, changes of level in the land are still taking place. The movements are of two kinds: —

1. Secular, or movements progressing slowly by the century.

2. Paroxysmal, — taking place suddenly, in connection usually with earthquakes.

1. *Secular.* — The secular movements which have been observed are confined to the middle and higher temperate latitudes, and are evidently a continuation of the series which characterized the earlier part of the Quaternary age.

The coasts of Sweden and Finland, on the Baltic, have been proved, by marks made under the direction of the Swedish government, to be slowly rising. The change is slight at Stockholm, but increases northward, and is felt even at the North Cape, — an extent, north and south, of one thousand miles. Lyell, in 1834, estimated the rise, at Uddevalla, at nearly or quite four feet in a century, and made it still greater to the north. The fact of the slow elevation was first suspected a century and a half since. Here, then, is slow movement by the century, such as characterized the great changes of level in past ages.

Beds of recent shells are found along the coast at many places, at heights from 100 to 700 feet. Part of these are of Quaternary date. Two miles north of Uddevalla, Lyell found barnacles on the rocks, over 100 feet above the sea; and there are shell-beds at a height of 400 feet. The former, at least, belong probably to the present era. Southwest of Stockholm, other beds of shells occur, and of the same dwarfish species that now live in the partly-freshened waters of the Bothnian Gulf.

There are also, near Stockholm, proofs of a former subsidence,

since fishing-huts were built on the coast. A fishing-hut, having a rude fireplace within, was struck, in digging a canal, at a depth of sixty feet. It is a common belief that over southern Sweden a very slow subsidence is now in progress.

In Greenland, a slow subsidence is taking place. For six hundred miles from Disco Bay, near 69° N., to the Firth of Igaliko, 60° 43′, the coast has been sinking for four centuries past. Old buildings and islands have been submerged; and the Moravian settlers have had to put down new poles for their boats, the old ones standing, Lyell observes, "as silent witnesses of the change."

On the North American coast, south of Greenland, along the coasts from Labrador to New Jersey, it is supposed that similar changes are going on. G. H. Cook concludes, from his observations, that a slow subsidence is in progress along the coasts of New Jersey, Long Island, and Martha's Vineyard; and, according to A. Gesner, the land is rising at St. John's, in New Brunswick; sinking at the island of Grand Manan; rising on the coast opposite, at Bathurst; sinking about the head of the Bay of Fundy, where there are regions of stumps, submerged thirty-five feet at high tide, and about the Basin of Mines in Nova Scotia, except, perhaps, on the south side; and rising at Prince Edward's Island.

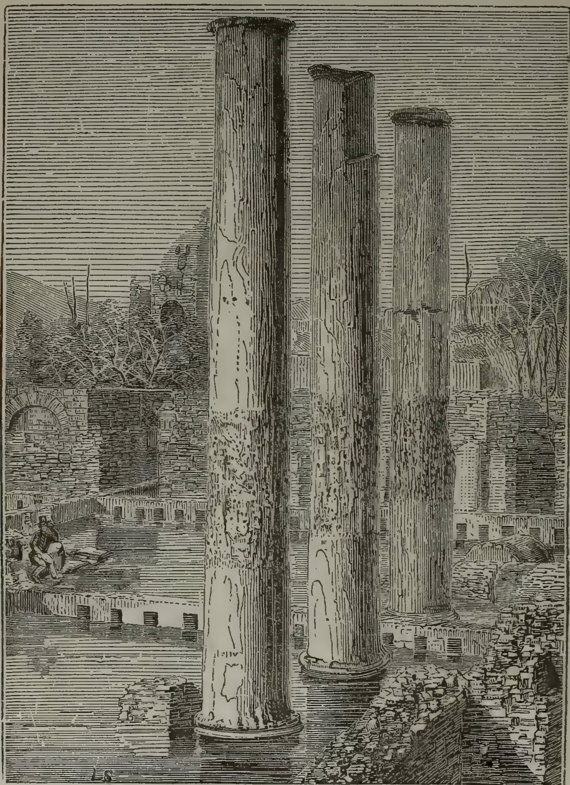
The Coral Islands of the Pacific are proofs of a great secular subsidence in that ocean. The line C C C (Physiographic Chart), between Pitcairn's Island and the Pelews, divides coral islands from those not coral; over the area north of it, to the Hawaian Islands, all the islands are atolls, excepting the Marquesas and three or four of the Carolines. If then the atolls, as will be shown on a future page, are registers of subsidence, a vast area has partaken in it, — measuring 6,000 miles in length (a fourth of the earth's circumference), and 1,000 to 2,000 in breadth. Just south of the line, there are extensive coral reefs; north of it, the atolls are large; but they diminish toward the equator, and mostly disappear north of it; and, as the smaller atolls indicate the greater amount of subsidence, and the absence of islands still more, the line A A may be regarded as the axial line of this great Pacific subsidence. The amount of this subsidence may be inferred, from the soundings near some of the islands, to be at least 3,000 feet. But, as two hundred islands have disappeared, and it is probable that some among them were at least as high as the average of existing high islands, the whole subsidence cannot be less than 6,000 feet. This sinking may have begun in the Tertiary era.

Since this subsidence ceased — for the wooded condition of the islands is proof of its having ceased — there have been many cases of isolated elevations. The following are some of the islands that have

been elevated: Oahu (Hawaian Islands), 25 feet; Molokai (ib.) 300 feet; Elizabeth Island, Paumotu Archipelago, 80 feet; Metia, or Aurora, 250 feet; Atiu, Hervey Group, 12 feet; Mangaia, 300 feet; Rurutu, 150 feet; Eua, Tonga Group, nearly 300; Vavau, 100; Savage Island, 100. More than twenty-five others have undergone some elevation.

2. *Paroxysmal.* — The changes of level about Pozzuoli, near Naples, at Cutch, in the Delta of the Indus, and on the Chilian coast,

Fig. 958.



Temple of Jupiter Serapis.

South America, are noted examples. The first appears to have been gradual in its progress; but, even if so, it is not properly secular, in the sense in which that term is used. The cases at Cutch and in Chili were connected with earthquakes; the other is in the volcanic region of southern Italy.

The temple of Jupiter Serapis at Pozzuoli (Fig. 958) was originally

134 feet long by 115 wide; and the roof was supported by forty-six columns, each forty-two feet high, and five feet in diameter. Three of the columns are now standing: they bear evidence, however, that they were once for a considerable time submerged to half their height. The lower twelve feet is smooth: for nine feet above this, they are penetrated by lithodomous or boring shells; and remains of the shells (a species now living in the Mediterranean) were found in the holes. The columns, when submerged, were consequently buried in the mud of the bottom for twelve feet, and were then surrounded by water nine feet deep. The pavement of the temple is now submerged. Five feet below it, there is a second pavement, proving that these oscillations had gone on before the temple was deserted by the Romans. It has been recently stated that, for some time previous to 1845, a slow sinking had been going on, and that since then there has been as gradual a rising.

At the earthquake in 1819, about the Delta of the Indus, an area of 2,000 square miles became an inland sea; and the fort and village of Sindree sunk till the tops of the houses were just above the water. Five and a half miles from Sindree, parallel with this sunken area, a region was elevated ten feet above the delta, fifty miles long and in some parts ten broad. The natives, with reference to its origin, call it Ullah Bund, or Mound of God. In 1838, the fort of Sindree was still half buried in the sea; and, during an earthquake in 1845, the Sindree Lake was turned into a salt marsh.

In 1822, the coast along by Concepcion and Valparaiso, for 1,200 miles, was shaken by an earthquake; and it has been estimated that the coast at Valparaiso was raised three or four feet. In February, 1835, another earthquake was felt from Copiapo to Chili, and east beyond the Andes to Mendoza. Captain Fitzroy states that there was an elevation of four or five feet at Talcahuano, which was reduced by April to two or three feet. The south side of the island of Santa Maria, near by, was raised eight feet, and the north ten; and beds of dead mussels were found on the rocks, ten feet above high-water mark.

Thus the earth, although in an important sense finished, is still undergoing changes, from paroxysmal movements and prolonged oscillations. The changes, while probably more restricted than in the ages of progress, are yet the same in kind.

III. GENERAL OBSERVATIONS ON THE CENOZOIC.

1. Time-ratios. — Using the same kind of data as on p. 381, for determining the relative lengths of the ages and periods, we have for the Tertiary period, in North America — in which the maximum

thickness of the deposits was fully 16,000 feet, with very little limestone — the length about that of the Mesozoic (p. 481). But, as the action of rivers during the Cenozoic greatly aided the ocean in wear and transportation, it is probable that this estimate is half too large.

The data for the Quaternary are very uncertain; its lapse of time is more plainly marked in the extent of the valleys made than in the thickness of the rock deposits. It must have been at least one-third as long as the Tertiary.

Adopting these conclusions, the ratio for the Paleozoic, Mesozoic, and Cenozoic would be 12 : 3 : 1.

2. Geography. — The geographical progress of the Tertiary and the Quaternary ages went forward in different directions.

A. *Tertiary Age.* — In the Tertiary, there was (1) the finishing of the rocky substratum of the continents; (2) the expansion of the continents nearly to their full limits, or their essentially permanent recovery from the waters of the ocean; (3) the elevation of many of the great mountains of the globe, or considerable portions of them, through a large part of their height, as the Alps, Pyrenees, Apennines, Himalayas, Andes, Rocky Mountains, the loftiest chains of the globe, — a result not finally completed until the close of the Tertiary.

In North America, there occurred a small extension of the continent, on the Atlantic and Gulf borders; a vast increase west of the Mississippi; a small rising of the land on the east and south; an elevation of 6,000 to 10,000 feet in the Rocky Mountains (nearly the whole height of the mass), and 3,000 feet or more on the Pacific border.

The system of progress during the Tertiary was in each respect a continuation of that which began with the Archæan era. In North America, it was enlargement and elevation, especially to the southeast, south, and southwest, from the original dry land of the Archæan (p. 160).

The mass of the earth above the ocean's level was increased two or three fold, between the beginning and the end of the Tertiary period.

B. *Quaternary Age.* — In the Quaternary, the great events were (1) the excavation of valleys over the lifted mountains and plains, and the shaping of the lofty summits; (2) the distribution of earth and gravel, covering and levelling the rugged surface of the earth, laying the foundation of prairies, and filling the broad valleys with alluvium; (3) the finishing of the valleys and lake-borders with a series of plains or terraces, and the extension of flats along the sea.

There were great oscillations of level in the Quaternary, as well as in the Tertiary; but those affecting the continents were mainly ***high-***

latitude oscillations, being most prominent over the colder latitudes of the globe, the cold-temperate and Arctic; (2) they were movements of the broad areas of the continents; (3) they brought no mountain ranges into existence.

According to the view presented in the preceding pages, there was (1) an upward oscillation over the higher latitudes, in the Glacial period; (2) a downward, introducing the Champlain period, and then (3) an upward of moderate extent, introducing the Recent period. The Champlain subsidence submerged the region about Montreal and the Ottawa, so that marine shell deposits were there formed, — an event which had not previously occurred since the Lower Helderberg period in the Silurian age (p. 215). It submerged a large part of Britain to 500–1,400 feet below its present level, and much also of Europe, thereby giving an opportunity for the deposition of the thick river-border formations that prevail so extensively. But the elevation closing the Champlain period appears to have gone on, in Europe, until the continent stood above its present level, and, in connection, a second Glacial epoch intervened, separating the Champlain and Recent periods; and it may be that North America also was raised to a higher level than now, though with less marked glacial effects (p. 561). Thus the course of the movements was diverse from that of earlier time, and so also their results.

During the Quaternary, *some of the most prominent dynamical agencies on the globe were intensified vastly beyond their former power:* —

(1.) Owing to the completion of the great mountain-chains and the expansion of the continents, the heights for condensing moisture, and the extent of slope for its accumulation into rivers, had augmented many fold. Moreover, through the union of lands before isolated by seas, into continental areas, the rivers draining immense regions were for the first time united into common trunks. The Quaternary was therefore eminently *the era of the first grand display of completed river-systems,* — of the first Amazon, Mississippi, Ganges, Indus, Nile, etc.

(2.) The elevation of the mountains to snowy altitudes made *glaciers* — powerful dynamical agents.

(3.) The increase of cold, and the existence finally of true frigid zones, due partly, at least, to an increase of polar lands after the close of the Cretaceous period and through the Tertiary, gave a vast extent to glaciers, rendering them possible in regions where otherwise they could not have existed.

(4.) The cause last mentioned also gave origin to *icebergs.*

Great rivers, glaciers, and icebergs were especially characteristic of the Quaternary; and the ice accomplished what was impossible for the

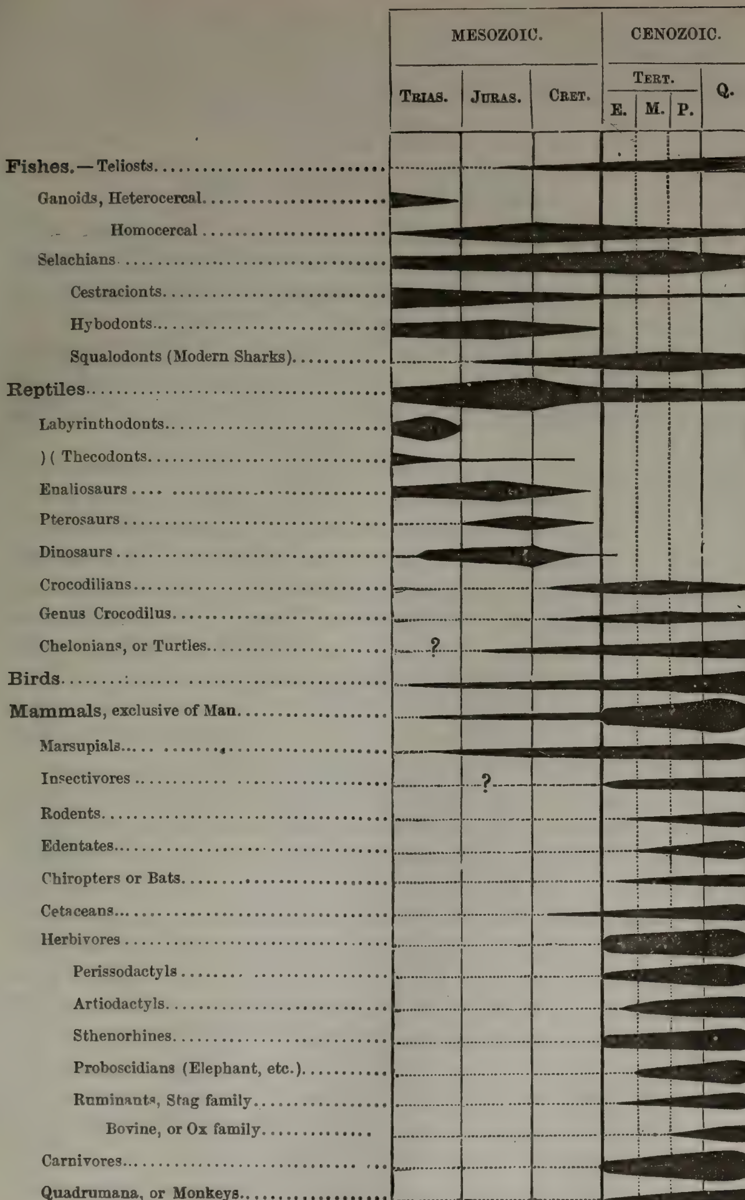
ocean. In no other period of geological history have so large masses of stone been moved over the earth's surface as in the Glacial and Champlain periods.

These Quaternary agencies were active everywhere over the continents, putting the finishing strokes to the nearly completed globe. There was a development of beauty as well as utility in all these later movements. Those conditions and special surface-details were developed that were most essential to the pastoral, agricultural, and intellectual pursuits which were about to commence.

3. Life. — *Grand characteristic of the Tertiary and Quaternary Ages.* — The prominent fact in the life is the expansion and culmination of the type of Mammals. This culmination, as regards brute Mammals, took place in the *Middle* Quaternary, when the Carnivores, Herbivores, Edentates, and Marsupials far exceeded in number and size those of the present time. It was the great feature, not of one continent alone, but of all the continents, and on each under its own peculiar type of Mammalian life.

Man appeared before the Champlain Mammals had gone. But an era of cold — the second glacial — after a while intervened; and then there went forward — partly, if not wholly, in consequence of the cold — the extermination of these gigantic species, leaving only smaller races for the era of man's development. In this, the true Human era, the Animal element is consequently no longer dominant, but Mind, in the possession of a being at the head of the kingdoms of life. The era bears the impress of its exalted characteristic, even in the diminished size of its beasts of prey.

Range of Vertebrate types. — The following table presents to the eye the range of the more common Vertebrate types, through the Mesozoic and Cenozoic, showing those which began in the Paleozoic, those which have their commencement, culmination, and end within these eras, and those which continue into the age of Man. The symbol) (signifies having biconcave vertebræ. Under Tertiary, the letters E., M., P. stand for Eocene, Miocene, Pliocene: Q. stands for Quaternary.


MESOZOIC.
CENOZOIC.
TRIAS.
JURAS.
CRET.
TERT.
E.
M.
P.
Q.
Fishes.—Teliosts
Ganoids, Heterocercal
Homocercal
Selachians
Cestracionts
Hybodonts
Squalodonts (Modern Sharks)
Reptiles
Labyrinthodonts
)(Thecodonts
Enaliosaurs
Pterosaurs
Dinosaurs
Crocodilians
Genus Crocodilus
Chelonians, or Turtles
?
Birds
Mammals, exclusive of Man
Marsupials
Insectivores
?
Rodents
Edentates
Chiropters or Bats
Cetaceans
Herbivores
Perissodactyls
Artiodactyls
Sthenorhines
Proboscidians (Elephant, etc.)
Ruminants, Stag family
Bovine, or Ox family
Carnivores
Quadrumana, or Monkeys

GENERAL OBSERVATIONS ON GEOLOGICAL HISTORY.

1. LENGTH OF GEOLOGICAL TIME.

On former pages (pp. 381, 585), estimates have been given of the relative lengths of the ages and periods, or their time-ratios. Future discovery will probably enable the geologist to determine these ratios with far greater certainty and precision.

Although Geology has no means of substituting positive lengths of time, in place of such ratios, it affords facts sufficient to prove the general proposition that *Time is long*. A few examples are here given.

Niagara has made its gorge by a slow process of excavation, and is still prolonging it toward Lake Erie. Near the fall, the gorge is 200 to 250 feet deep, and 160 feet at the fall, — the lower 80 feet shale, the upper 80 limestone. The waters wear out the shale, and thus undermine the limestone. The rocks dip fifteen feet in a mile up stream, so that the limestone at the fall becomes thicker, as retrocession goes on. The distance from Niagara to the Queenstown heights, which face the plain bordering Lake Ontario, is seven miles.

On both sides of the gorge near the whirlpool (three miles below the fall), and also at Goat Island, there are beds of recent lake-shells, *Unios*, *Melanias*, and *Paludinas*, the same kinds that live in still water near the entrance to the lake, and which are not found in the rapids. The lake, therefore, spread its still waters, when these beds were formed, over the gorge above the whirlpool. A tooth of a Mastodon has been found in the same beds. This locates the time of deposition in the Champlain period. Moreover, the waters would not have been set back to the height of these beds, unless they extended on below for at least six miles from the falls. Six miles of the gorge have then been excavated, since that Mastodon was alive. There are terraces in the shell deposits, showing changes of level in the lakes.

There is a lateral valley, leading from the whirlpool through the Queenstown precipice, at a point a few miles west of Lewiston. This valley is filled with Drift, as stated on page 556; and this blocking up of the channel forced it to open a new passage.

If, then, the falls have been receding six miles, and we can ascertain the probable rate of progress, we may approximate to the length of time it required. Hall and Lyell estimated the average rate at one foot a year, — which is certainly large. Mr. Desor concluded, after

his study of the falls, that it was "more nearly three feet a century than three feet a year." Taking the rate at one foot a year, the six miles will have required over 31,000 years; if at one inch a year, — which is eight and one third feet a century, — 380,000 years.

The rate at which coral reefs increase in height affords another mode of measuring the past. From calculations elsewhere stated by the author, it appears that the rate of increase of a coral reef probably is not over a sixteenth of an inch a year. Now, some reefs are at least 2,000 feet thick, which, at one sixteenth of an inch a year, corresponds to 384,000 years, or very nearly *a thousand years* for five feet of upward increase. If the progressing subsidence essential to the increasing thickness were slower than the most rapid rate at which the upward progress might take place, the time would be proportionally longer. The reefs may have been begun in the Tertiary.

The use of these numbers is simply to prove the proposition that Time is long, — very long, — even when the earth was hastening on toward its last age. And what, then, of the series of ages that lie back of this in time? Thousands of millions of years have been claimed by some geologists, for time since life began. Sir Wm. Thomson has reduced the estimate, on physical grounds, to one hundred millions of years as a maximum. If the time since the commencement of the Silurian were but forty-eight millions, the ratio 12 : 3 : 1, above deduced for Paleozoic, Mesozoic, and Cenozoic times, would give for each, severally, thirty-six millions, nine millions, and three millions, of years.

In calculations of elapsed time, from the thickness of formations, there is always great uncertainty, arising from the dependence of this thickness on a progressing subsidence. In the case of coral limestone, the data employed give the *least* possible time, as is obvious from the above. In estimates made from alluvial deposits, when the data are based on the thickness of the accumulations in a given number of years, — say the last 2,000 years, — this source of doubt affects the whole calculation, from its foundation, and renders it almost, if not quite, worthless. An estimate of the length of the Miocene epoch, made from data derived from observations on the deposits then forming in England, would have given no idea of the length of time required for the Miocene Molasse of Switzerland; and, in the same manner, any such data from observations at the present day must be equally fallacious. When the estimate, as from delta-deposits, is based on the amount of detritus discharged by a stream, it is of more value. But even here there is a source of great doubt, in our ignorance of the oscillations the continent may have undergone in past time, which, especially if an upward movement, would have affected the amount of discharge, and, if attended with glaciers, would have produced immensely larger depositions in a given time. This source of doubt affects also the calculations from the excavation of valleys.

2. GEOGRAPHICAL PROGRESS.

The system of oscillations and progress in North America during the ages, to the close of the Tertiary period, and the new system

which succeeded and characterized subsequent time, have been discussed in the course of the General Observations on the Archæan, Paleozoic, Mesozoic, and Cenozoic eras; and the reader is here referred to pp. 160, 389, and 520, a recapitulation in this place being unnecessary.

3. PROGRESS OF LIFE.

Several general principles connected with the progress of life have been illustrated in the course of the preceding history. They are here brought together in brief review.[1]

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[1] The following are some of the *Criteria of Rank* among Animals: —

(1.) Under any type, *water-species are inferior to land-species:* as the Seals to the terrestrial Carnivores; the water-articulates, or Worms and Crustaceans, to land-articulates, or Spiders and Insects.

(2.) *Species of a tribe bearing some of the characteristics of an inferior tribe or class are inferior species, and conversely.* — Thus, Amphibians show their inferiority to True Reptiles, in the young having gills, like Fishes; the early Thecodont Reptiles, inferiority to the later, in having biconcave vertebræ, like Fishes; the Marsupials and Edentates, inferiority to other Mammals, in having the sacrum consisting of only two united vertebræ, as in most Reptiles. On the contrary, the Dinosaurs show their superiority to other Saurians, in having the sacrum made of five (or six) vertebræ, as in the higher Mammals.

(3.) *As a species in development passes through successive stages of progress, relative grade in inferior species may often be determined by comparing their structures with these embryonic stages.* — As a many-jointed larve, without any distinction of thorax and abdomen, is the young state of an Insect, therefore Myriapods, or Centipedes, which have the same general form, are inferior to Insects. As a young living Gar has a vertebrated caudal lobe (making an accessory upper lobe to the tail), which it loses on becoming adult, therefore the older Ganoids, with vertebrated tails (or heterocercal), are inferior to the later, in which the tails are not vertebrated (or are homocercal). As the young of a Frog (a tadpole) has the tail and form of a Salamandrian, therefore the Salamandrians are inferior to Frogs. As the number of segments in the young of Insects often exceeds much that of the adult, therefore species of adult animals in which there is an excessive number of segments (beyond the typical number) have in this a mark of inferiority; and thus the Phyllopods and Trilobites among Crustaceans bear marks of inferiority, the typical number of segments in the abdomen of a Crustacean being but seven, and in the whole body twenty-one, — each pair of members corresponding to *one*, commencing with the eyes as the anterior.

Professor Agassiz has brought out and illustrated in his writings each of the above criteria.

(4.) *Species having the largest number of distinct segments in the posterior part of the body, or having the body posteriorly prolonged, are the inferior among those under any type.* — Shrimps and Lobsters are thus inferior to Crabs; Centipedes, to Insects; Salamandrians, or tailed Batrachians, to the Frogs, or tailless Batrachians; Snakes, to Lizards; the Ganoids with vertebrated tails, to those with non-vertebrated. It does not follow on this principle that Frogs, although tailless, are superior to Lizards: for they are of different types of structure.

(5.) *Species having the anterior part of the body most compacted or condensed in arrangement, or having the largest part of the body contributing to the functions of the head-extremity, are the superior, other things being equal.* — Thus, Man stands at the head of all Vertebrates, in having only the posterior limbs required for locomotion, the *anterior having higher uses;* and also in having the head most compacted in structure,

1. *The fact of Progress.* — The history with which the preceding pages are occupied has presented the grand fact that the system of life began in the simple sea-plant and the lower forms of animals, and ended in Man.

2. *The progress in climate and other conditions involved a concurrent progress from the inferior living species to the superior.* — The existence of a long marine era, through the Silurian and part of the Devonian ages, admitted of the existence chiefly of marine life. Hence the dominant type of the Silurian was the Molluscan, which, with the Radiate, is eminently marine. In addition, there were marine Articulates and marine Plants; and, when the Vertebrates began, it was with marine species, the Fishes. Thus the prevalence of waters involved inferiority of species. The increase of land, the gradual purification of the atmosphere, and the cooling of the globe, prepared the way for the higher species.

It is probable that the oceanic waters were also in an impure state, compared with the present, from containing an excess of salts of lime; and this also involved the existing of inferior species, — such as Crinoids, Corals, and Mollusks, a very large proportion of whose weight is in calcareous material. The removal of this excess of lime from the waters produced limestone strata, purified the waters, and fitted the oceans for other species.

The great prevalence, in the Primordial, of *Lingulæ* and some related Brachiopods, having shells containing a large amount of phosphate of lime, is further evidence of the greater density of the waters, and seems to indicate, as stated by Hunt, who first made known the fact, the presence of an excess of phosphates.

3. *The progress in climate and in the condition of the atmosphere and waters involved a localization of tribes in time, or chronographically, just as they are now localized by climate over the earth's surface, or geographically.* — Living species are always adapted to some special climate or condition of the globe; and, when this climate or condition had been passed in the earth's progress, the tribes fitted for it no longer

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and brought into the least compass consistent with the amount of brain. In the same manner, the Carnivores, among the large Mammals (Megasthenes), are superior to the Herbivores, the anterior limbs not having locomotion as their sole use, and the head being more compacted and condensed, for the size of brain. The highest Crabs, the Triangular, or Maioids, are superior in the same manner to the lower, and far more to the Lobster tribe and other Macrourans; descending in grade from the higher Crabs, the outer mouth-organs become more and more separated from the mouth, and, finally, in many Macrourans, they have the form of feet, thus passing from the head-series to the foot-series. Insects are, on this principle, — that of *Cephalization*, as it is called by the author, — superior as a class to Crustaceans, although of so much less size.

Condensation anteriorly and abbreviation posteriorly is the law of all progress in embryonic development, and also of relative rank among species of related groups.

existed. The culmination of the Reptilian and Molluscan types in the Reptilian age, and of Trilobites and Brachiopods in Paleozoic time, are examples. The former, when instituted, had those special relations to climate that made the Reptilian age the era of their culmination; just as, now, Palms and Bananas reach their perfection only in the equatorial zone; Figs, in the tropical; Myrtles and Laurels, in the subtropical; and Pines, in the subarctic. As there are now different zones of living species on going from the equator to the poles, so there were successive phases in the life of the world passed over from the Silurian — the period of universal temperate climate — to the present age of a frigid Arctic, and a mean temperature of 58° to 60° F. Climate was not the only cause; but it was one, and of great importance.

4. *The progress was in accordance with system.* — The species followed one another, according to a system of mutual relation or dependence, which is so profound and comprehensive that this progress is rightly spoken of as an evolution or development. This statement is sustained by the following considerations: —

(1.) The same grander types of structure that appeared in the Silurian age continued to be the grander types through all subsequent time. The Vertebrate type, for example, which was represented before the Silurian age closed, presented in its early species the fundamental elements of all Vertebrates; and future progress was manifested in modifications and complete developments of the fundamental idea. The two pairs of fins in Fishes represent the two pairs of limbs of higher species; an air-bladder, the lungs; a loose-bone in a closed cavity, the ear; and so on throughout the structure; and this is so completely true that the comparative anatomist, in order to understand the skeleton of the Mammal, or of Man, goes to the Fish for instruction. Thus the whole animal kingdom is the display of a few comprehensive structural types — the simpler forms of which appeared in early time, and the more complex came forth successively afterward. Some new organs were required in the highest manifestations of a type. But these were only developments through modification of the older, or better appliances evolved from the structure for carrying forward old processes.

Further, some of the old Silurian families of Invertebrates continued to exist through all time to the present. Thus, the most ancient type of Mollusks yet discovered, the Lingula family, is represented by species in our present seas; and so also the Discina and Nautilus families. Among Vertebrates, some of the ancient Gars are very much like our modern kinds, and one Triassic genus, *Ceratodus,* is still represented in Australian Seas. Such facts, coming up from the past,

through ages of unceasing change, declare emphatically the unity of system in Nature.

(2.) This truth is further manifested, in the fact of *a general parallelism between the progress of the earth's life and the successive phases in embryonic development.* The almost egg-like simplicity of the earliest living species of the rocks, — the Rhizopods among animals, and the Infusorial plants, — is the first illustration Geology presents. An animal without limbs, without any sense beyond the general sense of feeling, without a circulating system, without even a stomach, except such as it may extemporize when needed, and with the work of digestion, respiration, and reproduction performed by the same protoplasmic material that makes up the mass of the body of the infinitesimal Rhizopod, is, as to complexity of organization, but little removed from a germ; and such, we have reason to believe, was the beginning of the system of animal life.

Again, we find some of the earliest Crustaceans of the Phyllopod group closely resembling the young of some of the higher groups of living Crustaceans; and the early Fishes having cartilaginous skeletons, just as is now true of the higher Vertebrates when in the embryonic condition.

Again, the Gars of the present day have a vertebrated lobe to the tail, which they lose on becoming adults; and so the Gars had vertebrated tails in the young world, that is in Paleozoic time, which feature was lost in the progress of the Mesozoic era. The Amphibians afford a very similar illustration. So also the Birds; for, as the young often have a tail of several disconnected vertebræ, which contracts much on passing to the adult stage, so the earliest known of the Bird type had long, vertebrated tails, such as no modern Bird can boast or complain of.

Among the modern free Crinoids (Comatulids), the young, for a while, live attached to some support; and so, in the young world, the adult Crinoids had pedicels, and were attached species. In the existing Echini, as observed by A. Agassiz, the number of vertical series of plates in the shell of the young is often more than the adult number, twenty, and the adult shows this excess in the plates right around the mouth, the plates there being those of the young; and so, in the Echini of the young or Paleozoic world, the adults had an excessive number of series of plates, while later they have only the normal twenty.

(3.) The system of progress was *a system of successive specializations;* and in this it was parallel in idea with embryonic development; for, while in the earliest species all the functions were performed by one and the same protoplasmic mass, as the grade of species rose, these functions, one after another, had special organs to carry them forward.

(4.) It was a system of *progressive cephalization in the Animal structure;* and in this also it was parallel with embryonic development. Several of the facts already stated (p. 595) illustrate this. The head of an animal is always the part last perfected. In most Insects, even the highest, the young is a worm-like larve, with its several segments much alike in kind and functions; and the abdomen often serves for locomotion; but, in the adult, among the higher tribes, the abdomen and thorax have become distinct and greatly contracted; the abdomen has lost any locomotive appendages it had; and the head has become a well defined organ, of improved structure and better senses. At the same time, the thorax bears the only locomotive organs. Thus the abdomen has lost in forces, and the thorax and head have gained; and so the forces of the animal are in its development thrown toward the anterior extremity, and the structure is thereby cephalized. Now, in the history of the animal kingdom, the many-jointed Worms, with segments almost all alike, preceded the Insects, the higher and more cephalized forms of Articulates.

This principle might be extensively illustrated; for, throughout the animal kindom, wherever there has been progress, this progress has been attended with advance in stage of cephalization. Advance in cephalization necessarily involves corresponding improvements in structure.

Animals, high and low, are in contact with the outer world through their nervous system, and eminently by means of the cephalic ganglion (the brain in Vertebrates); and it is natural, therefore, that progress and cephalization should have gone forward together, the former involved in the latter.

In Man's structure, we see the last limit to which the law of cephalization can carry the system of life. The distinction is well illustrated in the grades of men. The retreating forehead, long occiput, projecting jaws, and longer fore-arm of the negro, are all marks of inferior cephalization. Progress in the race straightens up the forehead, and shortens in the jaws; and the abbreviation of the fore-arm also is a consequence of headward concentration in the forces of the system. Degradation is attended with a corresponding decephalization.

The idea of system in all structure, and of progress through the ages, under laws of specialization and cephalization, according to a scheme that may be compared to the opening of a flower, or the development of a germ, instead of being atheistic, is the only view of the history of life that is consistent with its Divine origin. Were there no such order of succession, no such unity of law and structure, this would be complete demonstration that a Being of infinite wisdom had not ordered or controlled events. Moreover, a Divinely appointed scheme of progress should exhibit, not merely system, but an exact reference to the external surroundings of the species, through the successive changes in the earth's physical history; and so completely, that the succession of life should be the same, whether carried forward by a system of natural causes under a Divine law established at the beginning, or by successive Divine acts.

Believing in the unity and wisdom of the Divine plan, it is evident that the discovery of the "missing links" in the succession of living species, or, in other words, of the gradations between types, is one of the grandest aims of geological science; for only after a thorough knowledge of all the facts will the system of life be completely understood.

5. *The comprehensive character of many of the groups in past time.* — This principle runs through all geological history, and is, in fact, involved in those already announced.

The examples of comprehensive types illustrate the general truth that the sub-kingdoms of life were present in early time, but in a more condensed or comprehensive form than now — the grander divisions having been defined, while the subordinate were often in combination with one another, and became afterward differentiated.

Among these comprehensive types, some are at or near a point of divergence of lines in the system of progress, as the Crinoids, near the point of divergence of Comatulids and Echinoids; some of the early Entomostracans, near that of modern Cyclopoids and Macrural Decapods; the earliest Tetradecapods, near that of Amphipods and Isopods; the earliest Decapods, near that of Macrourans and Brachyurans; early Neuropterous Insects, near that of true Neuropters and Orthopters; the Ganoids, near that of true Fishes and Reptiles, etc.

Others, like the Brachiopods, Trilobites, and Cycads, are lines that appear to continue undivided. There is no reason to suppose that a line from the Cycads led toward the Palms, the structure of the plants being wholly against it; the Trilobites, before they disappeared, were accompaniod by Tetradecapods; and there is nothing to support the idea that from the Trilobites there were lines to the Tetradecapods. The Brachiopods are the earliest known of Mollusks; but the line has no furcations afterward. The Ascidian group, as it is the most fundamental comprehensive type under Mollusks (and could not have been preserved in the rocks, since the body has no shell), may have been the precursor of both the Brachiopods and ordinary Mollusks.

6. *The progress involved not only the expansion of types, but also the culmination and decline of many, in the course of the history.* — (1.) The tribe of *Crinoids* began in the Primordial, culminated in the Carboniferous age, and is now nearly extinct.

(2.) *Brachiopods* have run a parallel course with the Crinoids; the families of the simple *Lingula* and *Discina*, with which the tribe began, and a few other kinds of low grade now remain; the genus *Leptæna*, of great prominence in Silurian and Devonian time, had its last species, as large as apple-seeds, in the Triassic.

(3.) *Trilobites* began at the same time, in loose-jointed or flabby species, with very large overgrown bodies and poor heads, passed their climax in number, and apparently in grade, in the Silurian, and disappeared, according to present evidence, at the close of the Paleozoic.

(4.) *Ganoid fishes* began in the Upper Silurian, with vertebrated tails; rose out of this inferior condition, and passed their climax, as to

numbers and variety of genera, in the Mesozoic; and now they are a nearly extinct group.

(5.) *Amphibians*, beginning in the Subcarboniferous, were, in the Carboniferous age and the Triassic period, the most prominent kind of Reptilian life, and of formidable size, with scaly armor, and teeth; after that, they dwindled; and now the tribe is represented only by little, inferior, naked-skinned Frogs and Salamanders.

(6.) *True Reptiles*, which began in the Carboniferous, had possession of the waters, the land, and the air, in the later Mesozoic, and far exceeded, in size, in variety, and vastly also in numbers, the Reptiles of the present era; great, swimming, snake-like Mosasaurs, having a length of seventy-five feet; swimming Enaliosaurs, of twenty to fifty feet; Dinosaurs, sometimes walking like bipeds, fifteen feet high; and Pterosaurs, flying bat-like, with, in some cases, a spread of wings of twenty to twenty-five feet.

(7.) *Mollusks* of the highest class — that of the Cephalopods — began in the Silurian, in kinds having straight, chambered shells; coiled forms followed; and then, in the Mesozoic, a wonderful variety of the most complex and largest kinds, with and without shells, existed; but nearly every genus with chambered external shells disappeared at the close of the Mesozoic; and now the only species are three or four of the Silurian and all-time genus, *Nautilus*.

These examples are enough to prove that the culmination of types, and then a dwindling in numbers, size, and grade, have always been involved in the system of progress. At the same time, many tribes, on the same principle, have their era of culmination now. This is true of Gasteropods, among Mollusks, of Birds, of the higher Insects, of Teliost Fishes, probably of Crustaceans. Mammals culminate now in Man, while brute Mammals reached their climax in the Champlain period of the Quaternary. Other examples of the condition of some of the more prominent tribes through time are presented in the tables on pages 386, 589.

7. (1.) *The earliest species under a type are not necessarily the lowest.* — If we may trust the records, Echinoderms, or the highest type of Radiates, were represented by species (Cystids and Crinids), long before the inferior type of Polyps existed; this can hardly be accounted for satisfactorily on the supposition that the earliest Polyps made no calcareous secretions, seeing that the ocean's waters were then eminently calcareous. (2.) The highest group of Cryptogams, the Ground Pines, were a prevailing form of terrestial vegetation, long before there were Mosses. (3.) There were huge Crocodilians in the world, long before there were limbless Snakes, like those of the present world. The great Labyrinthodonts were vastly superior in every re-

spect to modern Frogs and Salamanders. The Labyrinthodonts followed in the expanding line of the Ganoids; while the Frogs of modern time are an example of the degradation of an old type. Thus it is often the case that tribes have dwindled below the level of their first species. This necessarily follows from the principle stated on page 597. A tribe fitted to the equable climate of Paleozoic time would naturally have become degraded, under a later colder climate or other untoward circumstances.

8. *Peculiarities in the Fauna or Flora of a continent or region continue on through successive geological eras.* — Marked examples of a correspondence between the Quaternary and existing life of the continents are mentioned on page 571. Again, the Plants characteristic of the Cretaceous era, in North America, belonged mainly to families that are characteristic of the present time. Cases of this kind are numerous; and exceptions are largely due to migrations on one hand, and extinctions of groups on the other.

9. *The existence of Representative Species in different regions a possible consequence of migration.* — On each continent, there have been, in each geological period, not only some living species identical with those of another continent, but also a larger number that were closely similar without being quite identical, and which have hence been called *representative* species; at the same time, these species on either continent have continental or regional peculiarities that look like the impress of the region. Such parallel lines of representative species suggest the idea of origin through migration in a former period, and, after that, gradual alteration under the new regional influences. On the Atlantic and Pacific sides of Central America, there are many such representative species; and they have been regarded as an example under this principle.

The continents, as well as the oceans, radiate off from the Arctic zone; and, consequently, in the period of Glacial cold, Arctic species were forced far south along the several continents and oceans, some even to the Mediterranean (pp. 532, 533); leading thus to the distribution of the same species over widely different meridians and climates, and to the formation, in each, of new varieties. In the Miocene Tertiary, there was a comparatively mild climate in the Arctic zone; and forests abounded. As the climate became cooler with the progress of the Tertiary age (p. 526), the trees of the forests should have spread farther and farther south, along the different continents or meridians, according as the climate in either direction was congenial; similar kinds along eastern America and eastern Asia, because of the similarity of climate, and other kinds along other lines. A number of the genera and some of the species that then abounded in the Arctic are

actually distributed on the plan here indicated (p. 526). These facts suggest again migration and subsequent alteration, under the new regional influences as the cause, as urged by Professors Asa Gray and Heer.

10. *The existence of Representative Species not always a consequence of migration.* — On antipodal continents, — as, for example, North America and Australia, — there were in early time both identical and representative species. And now, in insular New Zealand, there are Crustaceans closely representative of some in its antipodes, insular Britain, in the case of which migration cannot be shown to be probable, or hardly in any way possible. Such facts suggest that the succession, in the species of different continents, may have been carried forward independently, even to the introduction of closely similar species.

11. *The transitions between Species, Genera, Tribes, etc., in geological history, are, with rare exceptions, abrupt.* — Geological history being prominently a history of the world's life, it is naturally looked to for facts respecting the first appearance of species, or the relations of species, by transitions or otherwise, to one another. A survey of the history finds little that is positive with regard to these transitions. It discovers, as all writers admit, almost no cases of the gradual passage of one species into another, not nearly as many or as close as exist in the present world. At the same time, the truth is apparent that the geological record is very imperfect, so much so as to greatly weaken all its testimony, with regard to abrupt transitions. It is imperfect, (1) because, under the most favorable circumstances, only a small part of the existing species could have been fossilized; (2) because in all lands there are great breaks in the series of rocks, as we know from comparing the rocks of different continents, and even different regions on the same continent; (3) because fossiliferous rocks are almost solely of aqueous origin, and consequently they contain exceedingly little of the terrestrial life of the ancient world; (4) because, whenever the land was at a higher level than the present, the marine strata then formed around it are now buried in the ocean and are therefore inaccessible; (5) because only a small part of the rocks of a country are open to view; and (6) because the continents have not been all thoroughly explored.

For example: (*a*) in North America, east of the Mississippi, there is not a trace of the life of the seas of the Triassic and Jurassic periods, two thirds of all Mesozoic time — the Triassic and what there is of Jurassic beds being of brackish-water or fresh-water origin. (*b*.) In the American Triassic and Jurassic beds, the jaw-bones of two marsupial Mammals have been found; and these two are the only relics of Mammals from the whole Mesozoic of the continent, when the

world was probably well peopled with them. (*c.*) Again, the Carboniferous age left testimony as to the kinds of vegetation that grew about and in its great marshes. But it affords nothing with regard to the forests that covered the higher parts of the continent in its higher latitudes, or west of the 100th meridian. Again, in the Triassic and Jurassic periods, the land was, we cannot doubt, as abundantly covered with vegetation as in the Carboniferous age; and yet we have only a very meagre record from the American rocks, and one but little better from those of Europe. (*d.*) The Jurassic period in Europe must have had in every part its numerous Birds; and yet we know them, thus far, only from the discovery of one single specimen at Solenhofen.

A broken record the geological undoubtedly is, especially for terrestial life. The marine life, particularly that of the Paleozoic, is better displayed; since marine formations were then more extensively in progress over the Continental seas than later; and the life of the world was also much alike in the two hemispheres.

Such facts invalidate the force of geological testimony, but without proving that abruptness of transition was not still a general fact.

(*e.*) The force of the evidence is further weakened by discoveries made from time to time, that diminish some of the wider gaps among the abrupt transitions. Thus, the Horse, an animal with one large toe making the whole foot, and no relics of other toes, excepting two slender bones either side, — called the *splint-bones*, — has been found (as shown on page 507) to have been preceded in Tertiary times by other Horses, with real toes in place of the splint-bones; and thus a transition has been made out toward related animals with a foot of four or five toes. Again, the Birds, now standing apart so stiffly, as animals with bills and feathers and short tails, in former times had teeth in their jaws (p. 466), and long tails (p. 446), and, moreover, in the Reptilian age, there were biped Reptiles, with the hollow bones and some other characteristics of Birds (p. 414).

Arctic America contains, in Tertiary fossils, remains of plants so much like species existing in the forests of both temperate North America and Europe (p. 526), that the former have been pronounced the undoubted progenitors of the latter.

But, while such discoveries have been made in many directions, they have still left, with rare exceptions, abrupt transitions between genera or groups; and in hardly a case in the animal kingdom have they yet filled out all gradations.

The admitted imperfections in geological history, owing to poor records, and these not half consulted, lead the cautious geologist to wait, before dogmatizing.

(*f.*) But there are a few breaks of extraordinary character, deserving special consideration. The first Vertebrates, Fishes, start off suddenly in the Upper Silurian; and no trace of connecting links with Mollusk or Articulate has been found. The Ascidian has been put forward as the origin; but no intermediate forms between the Ascidian and Vertebrate exist among fossils; and, moreover, as Verrill has observed, after a thorough study of the tribe, the alleged relation to the Vertebrates is without the slightest foundation in their structure. The modern *Amphioxus*, — a very small fish without a brain, — has been made to fill the gap. But, although seemingly fitted for the place, it may be only degradational, and of comparatively modern development. The rocks have given us no hint as to its existence in Silurian times, or that of any other transitional species. Thus the gap is yet large, and, considering that Silurian rocks have afforded various embryonic forms in the development of species of Trilobites, it is strange that nothing has been found to illustrate the successive steps in the origin of the grand sub-kingdom of Vertebrates. It is possible that further search may be successful.

In the Cretaceous formation of North America, leaves of plants of modern type — the Angiosperms, like the Willow, Elm, Magnolia, etc., and the Palms — occur, and exhibit a totally different character in forest vegetation from that of the preceding period; and the same abrupt transition has been observed in Europe and other countries. A long interval may have existed between the Jurassic and Cretaceous in some regions, but hardly in all; and if, after more complete investigation, this distinction of the Jurassic and Cretaceous periods remain, we may have to look to some other reason for this abrupt transition than that from imperfect records.

In the early Tertiary, the world, as the fossils show, was full of true Mammals, related to the Tapirs and other kinds, many of great size; while no such Mammal has yet been detected in any earlier beds. It is undoubtedly true that the break in the records, with regard to the era preceding the Tertiary, is great; but this fact does not supply all that Science needs for a perfectly confident explanation of the break in the system of Mammalian life. In the coal-bearing formation overlying the Cretaceous, in the Rocky Mountain region, there are the bones of Dinosaurs; while in the Eocene beds, resting on these, there are remains of a wonderful variety of Mammals, some of elephantine size. Probably a long time intervened between the eras of the coal-beds and of the Tertiary bone-beds. But however long the time that may be claimed, the abruptness of the transition is astounding, and needs facts for its full elucidation. The same abruptness in the introduction of the Tertiary Mammals occurs in the beds of other conti-

nents, as well tropical India as colder Europe. In some regions, the Cretaceous beds are of deep-water origin; and hence they are not the place to look for terrestrial fossils. But this is not true of the Rocky-Mountain or Atlantic-border deposits of North America, nor of those of many localities on other continents.

(*g.*) In the case of Man, the abruptness of transition is still more extraordinary, and especially because it occurs so near to the present time. In the highest Man-ape, the nearest allied of living species has the capacity of the cranium but thirty-four cubic inches; while the skeleton throughout is not fitted for an erect position, and the fore-limbs are essential to locomotion; but, in the lowest of existing men, the capacity of the cranium is sixty-eight cubic inches, every bone is made and adjusted for the erect position, and the fore-limbs, instead of being required in locomotion, are wholly taken from the ground, and have other higher uses. Forty years since, Schmerling found fossil bones of ancient Man in Europe; and for the past fifteen years active search has gone forward for the missing links; and still the lowest yet found, — and this probably not the oldest, — has a cranium of seventy-five cubic inches capacity. Some of the oldest yet discovered have a large cranium and a high facial angle, although rude in implements and mode of life. No remains bear evidence to less perfect erectness of structure than in civilized man, or to any nearer approach to the Man-ape in essential characteristics.

The existing Man-apes belong to lines that reached up to them as their ultimatum; but, of that line which is supposed to have reached upward to Man, not the first link below the lowest level of existing Man has yet been found. This is the more extraordinary, in view of the fact that, from the lowest limit in existing men, there are all possible gradations up to the highest; while, below that limit, there is an abrupt fall to the ape level, in which the cubic capacity of the brain is one half less. If the links ever existed, their annihilation without a relic is so extremely improbable that it may be pronounced impossible. Until some are found, Science cannot assert that they ever existed.

The facts which have been stated bear upon the question of the Origin of Species. In order to reach a probable solution of the great problem, various facts and principles from other sources have to be considered, whose discussion here would be out of place. In view of the whole subject, the following appear to be the conclusions most likely to be sustained by further research.

1. The evolution of the system of life went forward through the derivation of species from species, according to natural methods not

yet clearly understood, and with few occasions for supernatural intervention.[1]

2. The method of evolution admitted of abrupt transitions between species; as has been argued by Hyatt and Cope, from the abrupt transitions that occur in the development of animals that undergo metamorphosis, and the successive stages in the growth of many others.

3. External agencies or conditions, while capable of producing modifications of structure, have had no more power toward determining the directions of progress in the evolution, than they now have in determining the course of progress in development from a living germ.

4. For the development of Man, gifted with high reason and will, and thus made a power above Nature, there was required, as Wallace has urged, the special act of a Being above Nature, whose supreme will is not only the source of natural law, but the working force of Nature herself.

[1] There is here no discordance with the Biblical account of Creation, since, in it, there is one fiat for the first introduction of life, and only three others for that of the animal kingdom; and, moreover, the language implies growth for the rest, through law established by the fiats.

PART IV.

DYNAMICAL GEOLOGY.

DYNAMICAL GEOLOGY treats of the causes of events in the earth's geological progress.

These events include: the formation of all rocks, stratified and unstratified, with whatever they contain, from the earliest Archæan to the modern beds of gravel, sand, clay, and lava; the oscillations of the earth's crust; the increase of dry land, elevation of mountains, and elimination of the surface-features of the globe; the changes of climate; the changes of life.

The causes or agencies that have been engaged, exclusive of life, have acted for the most part through the atmosphere, waters, and rock-material. But they are based necessarily on the general powers of Nature, — Heat, Light, Electricity, and Attraction. These fundamental powers have their universal laws, — as the law of gravitation, according to which falling bodies move; the laws of chemical attraction, according to which compounds are formed and decompositions take place; the laws of cohesion or crystallization, according to which solidification produces crystals, or a crystalline structure; the laws of heat, as regards conduction, expansion, etc., and the influence of heat on chemical changes and growth; the laws of light, as to its nature, and its action in chemical changes and growth, etc.; the laws of electricity and magnetism: all of which the geologist cannot understand too well. But the discussion of these topics belongs properly to a treatise on Physics. The laws of solidification are, however, briefly considered in this place, on account of their bearing on the structure of rocks.

In addition to the general operation of forces, there are other actions, that may be embraced under the term *climatological*, which proceed from the systematic arrangement and movement of heat, light, moisture, and electricity about the sphere (causing zones of temperature, varieties of climate, etc.), and also from the systems of atmos-

pheric and oceanic circulation. The general facts on these topics are briefly stated on pp. 38–46, which may well be reviewed before proceeding with the following pages. In treatises on Physical Geography, these subjects may be studied at greater length, by the geological student, with much advantage.

The subject of dynamical geology is here treated under the following heads: —

1. Life; 2. Cohesive and Capillary attraction; 3. The Atmosphere; 4. Water; 5. Heat; 6. Consequences of the earth's cooling, and the Evolution of the general features of the globe; 7. In recapitulation, Effects referred to their Causes.

The chemistry of rocks, or the chemical processes concerned in their origin and metamorphism, embracing a consideration of Life, the Atmosphere, Water, Light, and Heat as chemical agents, would naturally constitute another section, under the title of Chemical Geology. But, since its proper elucidation would require a large amount of space, and its study a minute knowledge of the principles of Chemistry, the subject is not taken up in detail in this Manual. Some of the more common facts are mentioned, under the head of Water as a Chemical Agent (p. 702).

I. LIFE.

1. Protective Effects.

The protective effects of life come chiefly from vegetation.

1. Turf protects earthy slopes from the wearing action of rills that would gully out a bare surface; and even hard rocks receive protection in the same way.

2. Tufts of grass and other plants over sand-hills, as on sea-shores, bind down the moving sands.

3. Lines of vegetation along the banks of streams prevent wear during freshets. When the vegetation consists of shrubs or trees, the stems and trunks entangle and detain detritus and floating wood, and serve to increase the height of the margin of the stream.

4. Vegetation on the borders of a pond or bay serves in a similar manner as a protection against the feebler wave-action. In many tropical regions, plants growing at the water's edge, like the mangrove, drop new roots from the branches into the shallow water, which act like a thicket of brush-wood, to retain the floating leaves, stems, and detritus; and, as the water shallows, other roots are dropped farther out, which are attended with the same effect; and thus they keep moving outward, and subserve the double purpose of protecting and making land. The coarse salt-marsh grasses along sea-shores per-

form the same kinds of geological work, being very effectual agents in entangling detritus, and in protecting from erosion.

5. Patches of forest-trees, on the declivities in Alpine valleys, serve to turn the course of the descending avalanche, and entangle snows that, but for the presence of the trees, would only add to its extent; and in the Alps, such groves are usually guarded from destruction, with great care. Forests also retard the melting of snow and ice in spring, and thus lessen the devastations of floods. Earthworms transfer earth to the surface and loosen soils.

6. The calcareous Algæ, called Nullipores (p. 135), served to protect the margins of coral reefs from wear; and ordinary seaweeds often cover and protect the rocks of a coast nearly to high-tide level.

2. Transporting Effects.

1. Seeds caught in the hair or fur of animals, or contained in the mud adhering to their feet, are transported from place to place.

2. Seeds are eaten by animals as food, or in connection with their food, and are dropped in another region undigested.

3. Ova of fish, reptiles, and inferior animals are supposed to be transferred from one region to another by birds and other animals. Authenticated instances of this are wanting.

4. Floating logs and seaweeds carry Mollusks, Crustaceans, Worms, and other species from one region to another along the courses of marine currents. Sometimes land and fresh-water shells, etc., are borne from rivers into estuaries or the sea, there to become mingled with marine shells.

5. Migrating tribes of men carry, in their grain, or otherwise, the seeds of various weeds, and also, involuntarily, rats, mice, cockroaches, and smaller vermin; also insects injurious to vegetation, and other kinds. The origin of tribes may often be inferred from the species of plants and of domesticated and other animals found to have accompanied them.

3. Destructive Effects.

The destructive effects proceed either from living plants or animals, or from the products of decomposition.

1. The roots which come from the sprouting of a seed in the crevice of a rock, as they increase in size, act like wedges, in tending to press the rock apart; and, when the roots are of large size, masses tons in weight may be torn asunder; and, if on the edge of a precipice, the detached blocks may be pushed off, to fall to its base. This is one of the most effective causes of the destruction of rocks. Many regions

of massive and jointed rocks are thickly covered with huge blocks, looking like transported bowlders, which are the results of this kind of upturning. The opening of fissures by roots also gives access to moisture, and thus contributes further to rock destruction.

2. Boring animals, like the saxicavous Mollusks, make holes often as large as the finger, and sometimes larger, in limestone and other rocks, along some sea-shores. Species of *Saxicava*, *Pholas*, *Petricola*, *Lithodomus*, *Gastrochæna*, and even some Gasteropods, Barnacles, Annelids, Echini, and Sponges, have this power of boring into stone. Various species also bore into shells or corals. In seven years, Carrara marble, in the sea south of Long Island, became riddled with borings *made by a Sponge.* The Termites and many other insects, especially when in the larval state, the *Limnoria* among Crustaceans, and the *Teredo* among Mollusks, bore into wood.

3. The tunnelling of the earth done by small quadrupeds, as the Mole, and by Crustaceans like the Craw-fish, sometimes results in the draining of ponds, and the consequent excavation of gullies or gorges by the outflowing waters. The tunnelling of the levees of the Mississippi by Craw-fish is one prominent cause of breaks, and thereby of great floods over the country.

4. The decay of vegetation about rocks often produces carbonic acid or different vegetable acids, which become absorbed by the moisture of the soil, and thus penetrate the crevices of rocks and promote their decomposition. This is properly one of the chemical effects of life.

5. Animals using Mollusks and Echinoderms as food make great refuse-heaps, or beds of broken shells. The animals include Man, as well as other species; and the beds made by fishes off the coast of Maine, as described by Verrill (who has drawn attention to this mode of making broken shells), are of great extent. They might be taken for beach-deposits.

6. Fungi attack dead plants and animals, and rapidly destroy them.

7. The destruction also of the vegetation of a region by insect life, and that of animals by one another, are of geological importance.

4. Contributions to Rock Formations.

The capability, on the part of Life, of contributing to the material of rocks, depends on several considerations, of which the following are the more prominent: —

1. The conditions favoring or limiting growth and distribution,—that is, the laws of geographical distribution of living species.

2. The nature of different organic products, and the fitness of the species affording them for making fossils or rocks.

After discussing these subjects, some of the methods of contributing to rock-formations are mentioned under the heads, —

3. Methods of fossilization and concretion.
4. Examples of the formation of strata through the agency of Life.

1. *Geographical Distribution.*

The subject of the geographical distribution of plants and animals, though highly important in this connection, cannot be satisfactorily treated in a brief chapter; and the student is therefore referred to treatises on this branch of science. Its general principles and bearing are all that can here be explained.

A. *The distribution of terrestrial plants and animals* is limited by different causes.

1. *Climate.* — The temperature to which each is adapted in its nature determines, within certain limits, its position in the zones between the equator and the poles, and also, under any zone, its special altitude, between the level of the sea and the height of perpetual snow.

Meyen divides heights, under the equator, from the sea to the level of 16,200 feet, — that of perpetual snow, — into eight zones or regions, — beginning below, naming them from the characteristic plants: —

	Feet.
1. Palms and Bananas,	0
2. Tree-ferns and Firs,	2,020
3. Myrtles and Laurels,	4,050
4. Evergreen dicotyledonous trees,	6,120
5. European dicotyledonous trees,	8,100
6. Pines,	10,140
7. Rhododendrons,	12,150
8. Alpine plants,	14,170

The corresponding zones in latitude, at the sea level, — setting aside variations from special currents, are, —

1. Equatorial,	Lat. 0°–15°	5. Cold-temperate,	Lat. 45°–58°
2. Tropical,	15°–23°	6. Subarctic,	58°–66°
3. Subtropical,	23°–34°	7. Arctic,	66°–78°
4. Warm-temperate,	34°–45°	8. Polar,	78°–88°

Beyond 88°, vegetation is supposed to be at present wanting.

Temperature, during the period of flowering and fruiting of plants, and during the reproductive period of animals, often determines their geographical limits.

Again, the amount of moisture for which a species is made determines its position in either a moist or an arid region.

Each continent has its own characteristic climate, arising mainly out of its special combination of these two elements, temperature and moisture; and this is one source of the great diversity of life among the continents. Another point in which the climate of continents differs is the limit of extreme heat and cold. For example, North

America, owing to its extent in latitude, from the Arctic circle to the hot tropics, is remarkable for its very wide extremes. The severe cold of winter passes over the land to the far south, destroying whatever cannot stand its power; and the summer's intense heat sweeps back again, with a similar effect; so that the continent cannot grow as many kinds of terrestrial plants or animals as that on the opposite side of the Atlantic.

2. *Continental idiosyncrasies*, or peculiarities that cannot be referred to climate. Each continent has its characteristic types of plants and animals. The Marsupials, in Australia, and Edentates or Sloth tribe, in South America, are examples; the sedate Platyrrhine Monkeys, in South America, and the nimble frolicsome Catarrhines, in Africa, are others; so also the abundance of Humming-birds in the Occident, and their absence in the Orient. Examples might be mentioned indefinitely. Moreover, the range of animal life, or that of vegetable life, has often a continental feature.

3. *Diversities of soil.* — Some plants require wet soil, others moderately dry, others arid; some rich, others sandy, others a surface of rock; some the presence of limestone, others of rocks containing silica, etc.; some the presence of salt, or a salt marsh.

B. The *distribution of aquatic species* is determined — 1. By the *character of the water*, whether fresh, brackish, or salt, pure or impure from mixed sediment; and but few species adapted for one condition survive in the other. Hence, changing a salt lake to a fresh one, or even making an addition of fresh waters which exceeds much the amount lost by evaporation (and the reverse), will dwindle or destroy the living species. Most reef-forming corals grow in the purest ocean waters, where sediments make no encroachments; a few, including some of the *Porites*, survive where there is much sediment.

The Aral and Caspian probably made formerly one great salt sea: owing to the rivers that enter them, the living species are few. The shells are now of but twelve species, and mainly of the *Cardium* family, with *Mytilus edulis* and a *Dreissena* (Mytilus family); and only two are quoted from the Aral, — *Cardium edule* and *Adacna* (*Cardium*) *vitrea*. The Cardium and Mytilus families are hence capable of enduring very wide extremes in the saline condition of the waters. It is interesting to note that the earliest of American bivalves (Acephals) were of the Cardium family (genus *Conocardium*); and the Mytilus family was but little later in introduction.

Certain species are confined to excessively saline waters. *Artemiæ* (Crustaceans) are found in the salt and alkaline lakes of all the continents. The larves under several genera of Dipterous insects are other examples.

2. By *temperature*. — The *reef*-forming corals grow within 100 feet of the surface in the warmer ocean-waters, in which the mean surface-temperature for the coldest month does not fall below 68° F. So other species of shallow waters have their limiting temperatures, and the range for any kind is usually not over 15° or 20° F. For the

zones of surface-temperature see the Physiographic Chart, and pages 12–44.

As already explained, the temperature of the ocean is greatly influenced by the currents; and while tropical currents carry warm waters pole-ward, along certain courses determined by the outline of the oceanic basins, the cold polar currents sweep equator-ward over the ocean's broad bottom, nearing the surface chiefly on the west side of the ocean.

The *deep-sea temperature* at the ocean's bottom is generally about 35° F., and in parts of the polar seas and the courses of polar currents, as low as 28° F. But 40° to 45° F. is usually found in the tropics within 300 fathoms of the surface; and as low as 40° F. almost everywhere under 1300 fathoms. The bottom of the Atlantic along the margin of the basin washed by the Gulf Stream, between 60 and 150 fathoms in depth, and at 600 to 800 fathoms in British seas, where the temperature is mostly above 55°, literally swarms with life (A. Agassiz, Verrill, Wyville Thomson); and in greater and colder depths the species are little less abundant. Fishes, Crabs, and other Crustaceans, Echini, Star-fishes, Crinoids, Corals, sea Worms, some of the kinds of extraordinary size, occur to a depth of 10,000 to 13,000 feet, and many species are living at nearly 18,000 feet, and probably beyond. But the *species within the sweep of the warm current differ to a great extent from those in the colder waters*, so that there is a *warmer-water* and a *colder-water* section among the deep-sea species.

The Rhizopod shells or Foraminifers of the Globigerina ooze, and the Diatoms of siliceous deposits, are believed to have dropped to the bottom from near the surface, the living species, although pelagic, being confined to shallow depths.

Again, there are *species that grow in waters above the ordinary temperature.* Some of the simpler Algæ, and especially microscopic species, will grow in waters even hot.

At the Hot Springs ("Geysers"), on Pluton Creek, California, Prof. Wm. H. Brewer observed Confervæ, in waters heated to 140°–149° F., and simpler Algæ where the temperature was 200° F. At the same place, Dr. James Blake found two kinds of Confervæ, in a spring of the temperature of 198°, and many *Oscillatoriæ* and two Diatoms, in one of 174°. In the waters of Pluton Creek, of 112° F., the Algæ formed layers three inches thick. Dr. Blake also collected fifty species of Diatoms, from a spring in Pueblo Valley, Nevada, the temperature being 163° F.; and they were mostly identical with those of beds of infusorial earth in Utah.

The various hot springs of the several Geyser Basins, in the Yellowstone National Park, contain very various Confervoid forms. The hottest springs, up to 200° F., contain numerous, long, slender, white and yellow vegetable fibres, on undetermined relations, waving in the boiling eddies, and becoming buried in the siliceous deposits over the bottom, where they often form layers several inches thick. The bright green forms appear to be confined to lower temperatures. W. R. Taggart reports that, at the vents on the shores of Lewis's Lake, *leafy* vegetation is limited to temperatures below 120° (Hayden's Reports, 1871–2). Dr. Josiah Curtis found, in these hot springs, siliceous skeletons of very numerous Diatoms; but the *vegetable matter was wanting*, in all cases, where the temperature exceeded 96° F. So many different causes might introduce these skeletons to the hotter pools, that their presence has not necessarily any more significance than that of the grasshoppers and butterflies which are frequently found in the same pools. Living larves of *Helicopsyche* were found, by Mr. Taggart, in a spring having the temperature of 180°, into which, however, they might have crawled from the river, which was close by; so that the eggs were not necessarily laid at the temperature given.

At Baños, on Luzon, Phillipine Islands, the author observed feathery Confervæ, in waters heated to 160° F.

3. *By light.* — Light is the chief agent determining *distribution in depth* (Fuchs), temperature being subordinate to it.

Experiment has proved the presence of light to a depth of 43 to 50 fathoms, and the probability that only a little passes beyond this limit. To a depth of 40 fathoms, the species, as announced by Fuchs, are *species of the light*, while those below are relatively *species of the darkness.* The two ranges of species differ, although there is some commingling, especially between 30 and 90 fathoms. But each of these ranges of species is divided into a *warmer-water* and a *colder-water* section, as above explained.

Many of the deep-sea species are blind. But crabs with good eyes live at a depth of 10,000 feet, and shrimps at 17,700 feet. Since large numbers of the species (Star-fishes, Alcyonoid Corals, Crustaceans, Worms) are phosphorescent, the deep depths have been supposed to be lighted by this means.

Plants are eminently species of the light; sea-weeds grow mostly within 10 fathoms of the surface, and rarely beyond 30. A few cases have been reported of the simplest kinds of plants occurring at great depths.

Some continental species living in dark places, as caverns, are blind; e. g., the blind Fish and Crustaceans of the Mammoth Cave, etc.

4. By *freedom from rough mechanical agents, and the reverse.* — The occurrence of the siliceous sponges especially over the bed of the deep oceans, has been accounted for on the view that they are too delicate to exist where there is much movement in the waters. On the other hand, some Corals and other species seem to thrive best amid the breakers.

5. By *the character of the bottom or shores*, whether rocky, sandy, or muddy.

2. *The nature of different organic products, and the fitness of the species affording them for making fossils and rocks.*

(*a.*) *Nature of the organic products contributed to rock-formations.* — Some of the general facts, relating to the nature of the organic products contributed by Life to the rocks, are mentioned on pages 59 to 62. The following are additional facts: —

Plants afford, besides carbon, oxygen, hydrogen, potash, and soda, with some sulphur and nitrogen. Carbonic acid is one of the important results of their decomposition.

Animal membranes and oil decompose, and pass off for the most part as gases. Portions of the carbon and hydrogen often remain in the bed in which they are buried, giving it a dark color, or making sometimes mineral oil or coal. Impressions of the soft parts of animals, as of some Cephalopods, and the membranous part of the wings of Pterodactyls, have been found in rocks; but they are very rare.

The tissues that penetrate shells and bones are sometimes in part retained by the ancient fossil. Two cases are mentioned by Barrande, of the conversion of the animal material, within a Lower Silurian *Orthoceras*, into *adipocere* (an animal substance having the appearance of spermaceti); and he speaks of them as the oldest *mummies* ever exhumed.

A small percentage of phosphates and fluorids is derived from decomposing animal tissues.

The Excrements of animals afford a considerable amount of phosphates, and, by decomposition, ammoniacal compounds, as in the case of guano. The amount of phosphates, from the life which swarms in some muddy sea-bottoms and shores, must be large. For analyses of Coprolites, see page 61.

Bones are combined with so large an amount of animal gelatine that they are the food of various animals; and this is a great source of their destruction. Again, when the animal matter decays, the bones are left very fragile, unless hardened anew by a substitution of mineral matter. In the Cartilaginous fishes, the backbone, when it fails wholly of stony material, is not found fossil, as in most fossil Ganoids.

The teeth of Vertebrates contain much less animal matter than bones, and also a coating of enamel, in which there is considerable phosphate of lime. They are therefore exceedingly durable, and the most abundant of the remains of many species. The *bony enamelled scales* of Ganoid fishes are also phosphatic, and equally enduring, differing much in this respect from the membranous scales of Teliosts.

(*b.*) The fitness of species for becoming fossilized or concreted into rocks depends in part on *their place and habits of growth.*

Aquatic species of plants and animals are those most likely to become fossils, and so to contribute to rock-formations; and, next, those that live in marshes, or along shores or the borders of marshes. The reasons are two: (1) Because almost all fossiliferous rocks are of aqueous or marsh origin; and (2) because organisms buried under water, or in wet deposits, are preserved from that complete decomposition which many are liable to when exposed on the dry soil, and are protected also from other sources of destruction. In North America, during the Cretaceous period, the dry portions of the continent, east of the Mississippi (see map, p. 479), were in all probability covered with vegetation as densely as now; and yet we have no remains of it, excepting the few in the Cretaceous beds of the Atlantic and Gulf borders. In the Pliocene Tertiary, the species of plants and birds may have been at least half as numerous as now. Yet a few hundreds of the former and hardly a score of the latter are all that have thus far been found fossil. The natural inference from these facts is that, while we may conclude that we have a fair representation, in known fossils, of the marine life of the globe, we know very little of its terrestrial life, — enough to assure us of its general character, but not enough for any estimates of the number of living species over the land.

Plants and all animal matter pass off in gases, when exposed in the atmosphere or in dry earth; and bones and shells become slowly removed in solution, when buried in sands through which waters may percolate. Bones buried in wet deposits, especially of clay, are sealed from the atmosphere, and may remain with little change, except a more or less complete loss of the animal portion. Mastodons have been mired in marshes, and thus have been preserved to the present time; while the thousands that died over the dry plains and hills have left no relics.

Among terrestrial Articulates, the species of Insects that frequent marshy regions, and especially those whose larves live in the water, are the most common fossils, as the *Neuropters;* while Spiders, and the Insects that live about the flowers of the land, are of rare occurrence. Waders, among Birds, are more likely to become buried and pre-

served, than those which frequent dry forests. But, whatever their habits, birds are among the rarest of fossils, because they usually die on the land, are sought for as food by numberless other species, and have slender hollow bones that are easily destroyed.

Vertebrate animals, as fishes, reptiles, etc., which fall to pieces when the animal portion is removed, require speedy burial after death, to escape destruction from this source as well as from animals that would prey upon them.

Fishes of the open ocean, having the means of easy locomotion through the waters, would be less liable to destruction from changes of level in the land than the Mollusks of a coast; and hence some of the Sharks of the Tertiary continue through two or three periods.

The animals generally of the ocean are little liable to extermination from changes of climate over the land; and hence *some* marine invertebrate species of the early Tertiary, *many* of the later, and *all* of the Quaternary, have continued on until now, while, as regards terrestrial animal life, there have been in this interval many successive faunas.

(*c.*) *The lowest species of life are the best rock-makers*, especially Corals, Crinoids, Mollusks, Rhizopods, Diatoms, and Coccoliths; for the reason that only the simplest kinds of life can be mostly of stone, and still perform all their functions. Multiplication of bulk for bulk is more rapid with the minute and simple species than with the higher kinds; for all animals grow principally by the multiplication of cells; and, when single cells or minute groups of them, as in the Rhizopods, are independent animals, the increase may still be the same in rate per cubic foot, or even much more rapid, on account of the simplicity of structure.

3. *Methods of Fossilization and Accumulation.*

A. *Fossilization.* — In the simplest kind of fossilization, there is merely a burial of the relic in earth or accumulating detritus, where it undergoes no change. Examples of this kind are not common. Siliceous Diatoms and flint implements are among them.

In general, there is a change of some kind; usually, either a loss, by decomposition of the less enduring part of the organic relic, with sometimes the forming of new products in the course of the decomposition, or an alteration, through chemical means, changing the texture of the fossil, or petrifying it, as in the turning of wood into stone.

The change may consist in a fading or blanching of the original colors; in a partial or complete loss of the decomposable animal portion of the bone or shell; a similar loss of part of the mineral ingredients, by solvent waters, as of the phosphates and fluorids of a bone or shell; or a general alteration of the original organism, leaving behind only one or two ingredients of the whole; or a combining of the old elements into new compounds, as when a plant decays and changes to coal or one or more carbohydrogens, a resin to amber, animal matter to adipocere.

The change may be merely one of crystallization. The carbonate of lime of shells is often partly in the state of aragonite; and, when so, there is usually a change, in which the whole becomes common or rhombohedral carbonate of lime (calcite). Sometimes, the compact condition of the original fossil is altered to one with the perfect cleavage of calcite, as often happens in the columns or plates of Crinoids and the spines of Echinoids.

The change often consists in the reception of new mineral matter into the pores or cellules of the fossil, as when bones are penetrated by limestone or oxyd of iron.

The change is frequently a true petrifaction, in which there is a substitution of new mineral material for the original; as when a shell, coral, or wood is changed to a siliceous fossil, through a process in which the organism was subjected to the action of waters containing silica in solution. In other cases, the organism becomes changed to carbonate of lime, as in much petrified wood; and in others, to oxyd of iron and pyrites; and more rarely to fluor spar, heavy spar, or phosphate of lime.

The mineral matter first fills the cells of the wood, and then takes the place of each particle as it decomposes and passes away, until finally the original material is all gone. Some fossil logs are carbonized at one end and silicified at the other.

In many silicified shells, stems of Crinoids, etc., in the Subcarboniferous rocks of Illinois and Indiana, the shell or stem has been split open, and much enlarged, by the infiltrating silica; owing apparently to successive depositions of silica between the shell and the first-formed siliceous layer within the cavity, as the silicifying process went forward.

The silica in most siliceous petrifactions has come from siliceous organisms associated with the fossil in the original deposit.

B. *Accumulation into Beds.* Calcareous remains of organisms, as shells, corals, etc., have very frequently been ground up by the action of waves or by currents of water, and thus reduced to a calcareous earth, — the solidification of which (as explained on p. 619), has made limestones.

When the fossils are minute, like Rhizopods and Diatoms, the simple concretion of the shells will make a solid rock, as in the case of chalk and flint (p. 478).

Ehrenberg estimates that about 18,000 cubic feet of siliceous organisms annually form in the harbor of Wismar, in the Baltic; and he has also found that similar accumulations are going on in the mud of American and other harbors.

The bed of *Rhizopods* accumulating in the North Atlantic, mentioned on page 477, contains, according to Huxley, about eighty five per cent. of these calcareous shells, mostly of the genus *Globigerina*, besides some siliceous Diatoms: it has probably a breadth (between Ireland and Newfoundland) of 1,300 miles, and extends at least some hundreds of miles to the south. Ehrenberg found, in a specimen examined by him, eighty-five species of calcareous Rhizopods, sixteen of Polycystines, and seventeen of Diatoms, with only a few arenaceous grains not of organic origin.

The siliceous shells of the microscopic *Polycystines* have been found not only in the frigid Sea of Kamtchatka (see Amer. Jour. Sci., II. xxii. pl. 1, for figures) and the North Atlantic, but also in the South Pacific, on both coasts of the Atlantic, in the Mediterranean, and, within the tropics, at Barbadoes, in the West Indies, and the Nicobar Islands, in the East Indies. Ehrenberg has named 282 species from a marl-like deposit at Barbadoes, considered as Tertiary, and 100 species from the Nicobar Islands, part of them identical with those of Barbadoes.

But, when the fossils are comparatively large, as ordinary corals and shells, the intervals between them must be filled with earth of some kind, derived from the wearing action of the waters. It may be the mud or detritus from rivers or from wave-action along sea-shores; but, when calcareous, it has evidently come from the wear of the shells, corals, or crinoids themselves; and hence any limestone rock, made up of large shells, corals, or crinoids, which has the interstices

thus filled in with limestone, bears probably evidence in itself that it has been formed, not in the deep ocean, but within the reach of current or wave action.

The kinds of limestone made through the agency of life include soft marl or calcareous earth, chalk, compact limestone, sometimes oölitic or concretionary (p. 63), of white, gray, bluish, blackish, and other colors, — the dark colors mostly due to the presence of carbon, from animal or vegetable decomposition.

4. *Examples of the Formation of Strata through the Agency of Life.*

1. Peat Formations.

Peat is an accumulation of half-decomposed vegetable matter, formed in wet or swampy places. In temperate climates, it is due mainly to the growth of spongy Mosses, of the genus *Sphagnum*. This plant forms a loose turf, and has the property of dying at the extremities of the roots, as it increases above; and it thus may gradually form a bed of great thickness. Moreover, it is very absorbent of moisture. In some limestone regions, the Sphagnous mosses are replaced by species of *Hypnum*, as in Iowa. The roots and leaves of other plants, or their branches and stumps, and any other vegetation present, may contribute to the accumulating bed. The carcasses and excrements of animals at times become included. Dust may also be blown over the marsh by the winds.

In wet parts of Alpine regions, there are various flowering plants which grow in the form of a close turf, and give rise to beds of peat, like the moss. In Fuegia, although not south of the parallel of 56°, there are large marshes of such Alpine plants, the mean temperature being about 40° F. On the Chatham Islands (380 miles east of New Zealand), peat thus formed has a depth of fifty feet.

The dead and wet vegetable mass slowly undergoes a change, becoming an imperfect coal, of a brownish-black color, loose in texture, and often friable, although commonly penetrated with rootlets. In the change, the woody fibre loses a part of its gases; but, unlike coal, it still contains usually twenty-five to thirty-three per cent. of oxygen. Occasionally, it is nearly a true coal.

Peat-beds cover large surfaces of some countries, and occasionally have a thickness of forty or fifty feet. One-tenth of Ireland is covered by them; and one of the "mosses" of the Shannon is stated to be fifty miles long and two or three broad. A marsh near the mouth of the Loire is described by Blavier as more than fifty leagues in circumference. Over many parts of New England and other portions of North America, there are extensive beds. The amount in Massa-

chusetts alone has been estimated to exceed 120,000,000 of cords. Many of the marshes were originally ponds or shallow lakes, and gradually became swamps, as the water, from some cause, diminished in depth. The peat is often underlaid by a bed of whitish shell-marl, consisting of fresh-water shells — mostly species of *Sphærium*, *Limnæa*, *Physa*, and *Planorbis* — which were living in the lake. There are often also, especially in regions of siliceous or metamorphic rocks, beds of a white chalky character, made of the siliceous shields of Diatoms.

Peat is used for fuel and also as a fertilizer. When prepared for burning, it is cut into large blocks, and dried in the sun. It is sometimes pressed, in order to serve as fuel for steam-engines. *Muck* is another name for peat, especially impure kinds, when employed as a manure; any black swamp-earth consisting largely of decomposed vegetable matter is so called.

Peat-beds sometimes contain standing trees, and entire skeletons of animals that had sunk in the swamp. The peat-waters have an antiseptic power. They consequently tend to prevent complete decay of the vegetable matter of the peat bed; and flesh is sometimes changed by the burial into adipocere.

2. Coral Formations.

Coral formations are made mainly from the calcareous secretions of coral-making polyps, and are confined to the warmer latitudes of the globe.

Kinds. — Coral formations, while of one general mode of origin, are of two kinds: —

1. *Coral islands.* — Isolated coral formations in the open sea.
2. *Coral reefs.* — Banks of coral, bordering other lands or islands.

Distribution. — The limiting temperature of reef-forming corals is about 68° F.; that is, they do not flourish where the mean temperature of any month of the year is below 68°. The extent of the Coral seas is shown by the position of the north and south lines of 68° F., on the Physiographic Chart, as already pointed out.

The *exclusion of corals* from certain tropical coasts is owing to different causes. — (1.) The cold extratropical oceanic currents, as in the case of western South America (see chart). (2.) Muddy or alluvial shores, or the emptying of large rivers; for coral-polyps require clear sea-water and generally a solid foundation to build upon. (3.) The presence of volcanic action, which, through occasional submarine action, destroys the life of a coast. (4.) The depth of water on precipitous shores; for the reef-corals do not grow where the depth exceeds one hundred feet.

For the last-mentioned reason, reefs are prevented from commencing

to form in the deep ocean. The notion that coral islands are rising from its depths has no support in facts: they must have the land within a few fathoms of the surface, to begin upon.

Coral formations are most abundant in the tropical Pacific, where there are two hundred and ninety coral islands, besides extensive reefs around other islands. The Paumotu Archipelago, east of Tahiti, contains between seventy and eighty coral islands; the Carolines, including the Radack, Ralick, and Gilbert groups, as many more; and others are distributed over the intermediate region. The Tahitian, Samoan, and Feejee Islands are famous for their reefs; also New Caledonia and the islands to the northwest. There are reefs also about some of the Hawaiian Islands. The Laccadives and Maldives, in the Indian Ocean, are among the largest coral islands in the world. The East Indies, the eastern coast of Africa, the West Indies, and southern Florida abound in reefs; and Bermuda, in latitude 32° N., is a coral group. Reef-forming corals are absent from western America, except along the coasts of Central America, and as far north as the Gulf of California, and mostly from western Africa, on account of the cold extratropical currents that flow toward the equator: for the same reason, there are no reefs on the coast of China. (See the Physiographic Chart.)

1. Coral Islands.

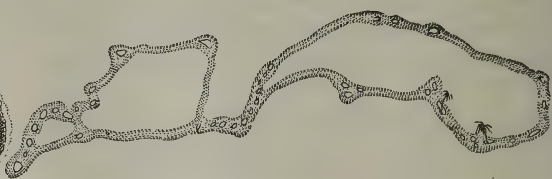
Forms. — *Atolls.* — A coral island commonly consists of a narrow rim of reef, surrounding a lagoon, as illustrated in the annexed sketch (Fig. 960). Such islands are called *atolls*, — a name of Maldive origin.

Fig. 960.

Coral island, or atoll.

Maps of two atolls are given in Figs. 961, 962, showing the rim of coral reef, the salt-water lake, or lagoon, and the variations of form in these islands. They are never circular. The size varies from a length of fifty miles to two or three; and, when quite small, the lagoon is wanting, or is represented only by a dry depression.

Fig. 961. Fig. 962.



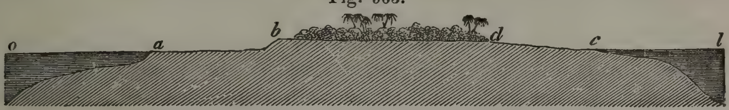
Atolls. — Fig. 961, Apia, one of the Gilbert Islands; 962, Menchikoff, one of the Carolines.

The reef is usually to a large extent bare coral rock, swept by the waves at high tide. In some, the dry land is confined to a few isolated points, as in Menchikoff Island, of the Caroline group (Fig. 962); in

others, one side is wooded continuously, or nearly so, while the other is mostly bare, or is a string of green islets, as in Fig. 961, representing Apia, one of the Gilbert Islands. The higher or wooded side is that to the windward, unless it happens to be under the lee of another island. On the leeward side, channels often open through to the lagoon (*e*, Fig. 961), which, when deep enough for shipping, make the atoll a harbor ; and some of these coral-girt harbors in mid-ocean are large enough to hold all the fleets of the world.

Fig. 963 represents a section of an island, from the ocean (*o*) to the lagoon (*l*). On the ocean side, from *o* to *a*, there is shallow water for some distance out (it may be a quarter or half a mile or more) ; and, where not too deep (not over one hundred feet), the bottom is covered here and there with growing corals. Between *a* and *b* there is a platform of coral rock, mostly bare at low tide, but covered at high, having

Fig. 963.



Section of a coral island, from the ocean (*o*) to the lagoon (*l*).

a width usually of about a hundred yards: there are shallow pools in many parts of it, abounding in living Corals of various hues, Actiniæ (Sea-anemones), Star-fishes, Sponges, Shells, Shrimps and other kinds of tropical life: toward the outer margin, it is quite cavernous; and the holes are frequented by Crabs, Fishes, etc. At *b* is the white beach, six or eight feet high, made of coral sand or pebbles and worn shells : *b* to *d* is the wooded portion of the island. The whole width, from the beach (*b*) to the lagoon (*c*), is commonly not over three or four hundred yards. At *c* is the beach on the lagoon side, and the commencement of the lagoon. Corals grow over portions of the lagoon, — although, in general, a large part of the bottom, both of the lagoon and of the sea outside, is of coral sand.

Beyond a depth of one hundred feet, there are no growing corals, except some kinds that enter but sparingly into the structure of reefs, the largest of which are the *Dendrophylliæ.*

Coral-reef Rock. — The rock forming the coral platform and other parts of the solid reef is a white limestone, made out of corals and shells. Its composition is like that of ordinary limestones.

In some parts, it contains the corals imbedded ; but, in others, it is perfectly compact, without a fossil of any kind, unless an occasional shell. In no case is it chalk. The compact non-fossiliferous kinds are formed in the lagoons or sheltered channels ; the kinds made of broken corals, on the seashore side, in the face of the waves ; those

made of corals standing as they grew, in sheltered waters, where the sea has free access.

The following are the principal kinds of coral rocks: —

1. A fine-grained, compact, and clinking limestone, as solid and flint-like in fracture as any Silurian limestone, and with rarely a shell or fragment of coral.

This variety is very common; and, where coral reefs or islands have been elevated, it often makes up the mass of the rock exposed to view. The absence of fossils, while the rock was evidently made out of corals and shells, is a remarkable and instructive fact.

2. A compact oölyte, consisting of rounded concretionary grains, and generally without any distinct fossils.

3. A rock equally compact and hard with No. 1, but containing imbedded fragments of corals and some shells.

4. A conglomerate of broken corals and shells, with little else, — very firm and solid; many of the corals several cubic feet in size.

5. A rock consisting of corals standing as they grew, with the interstices filled in with coral sand, shells, and fragments. In general, the rock is exceedingly solid; but in some cases the interstices are but loosely filled.

Coral Beach-rock. — The beach-rock is made from the loose coral sands of the shores, which are thrown up by the waves and winds. The sands become cemented into a porous sandstone, or, where pebbly, into a coral pudding-stone. It forms layers, or a laminated bed, along the beach of the lagoon, and also on the sea-shore side, sloping generally at an angle of five to eight degrees toward the water, but sometimes at a larger angle, this depending on the slope of the beach at the place.

Formation of the Coral Reef. — A reef-region is a plantation of living corals, in which various species are growing together, — at one place, in crowded thickets, at another, in scattered clumps, over fields of coral sand. There is the same kind of diversity that exists in the distribution of vegetation over the land. Some of the kinds branch like trees of small size, or shrubs (*Madreporæ*); others form closely-branched tufts (*Pocilliporæ*, many *Porites*); others resemble clustered leaves (*Merulinæ*, *Montiporæ*), or tufts of pinks (*Tubiporæ*), or lichens and fungi (*Agariciæ*, etc.); others grow in hemispherical or subglobular forms (*Astræœ*, *Meandrinæ* and some *Porites*); and others are groups of slender, brilliantly-colored twigs (*Gorgoniæ*).

When alive in the water, all these corals are covered throughout with expanded polyps, emulating in beauty of form and colors the flowers of the land.

Each of the polyp-cells in these corals corresponds to a separate animal or polyp (p. 130). In the *Madreporæ*, the polyps when expanded have twelve rays, or tentacles, and a diameter of an eighth to a quarter of an inch. Those of the *Pocilliporæ* and *Porites* are also twelve-rayed, but smaller. The *Astræœ* have an indefinite number of rays, or tentacles: in some species of the family, the expanded flower-like polyp is an inch or more in diameter. In the *Meandrinæ* and related kinds, the polyps coalesce in

fines; there is a series of mouths along the centre of each furrow, and a border of tentacles either side. The *Fungiæ* have the form of broad, circular, or oblong disks; the disk corresponds to a single polyp, and has a diameter in some cases of ten or twelve inches.

In the *Milleporæ*, as stated on page 130, the animals are *Acalephs*, and not true Polyps.

Corals of the different groups here mentioned grow together promiscuously at different depths, up to low-tide level. The largest *Astræœ*, *Meandrinæ*, and *Porites*, with many *Madreporæ* and other kinds, have been seen by the author constituting the *upper part* of the growing reef. At Tongatabu, there were single masses of *Porites*, twenty-five feet in diameter, along with *Astrææ* and *Meandrinæ*, ten to fifteen feet. But, while these different groups do not correspond to different zones in depth, there are, without doubt, species in them which belong to the deeper waters, and others to the more shallow.

The *Porites*, with some species of the *Astræa*, *Madrepora*, and *Pocillipora* groups, continue to grow a little above low-tide level, equal to about one-third the height of the tide, — as they will endure a temporary exposure to the sun without serious injury. The *Porites* are an especially hardy group; for the corals suffer less from impurity or silt in the waters than the species of other groups.

The polyp-corals have the power of growing indefinitely upward, while death is going on at equal rate, either at the base of the structure (as in the moss of which peat is made) or through its interior, and are only stopped in upward progress by reaching the surface of the water. The hemispherical *Astrææ*, many feet in diameter, although covered throughout with living polyps, may be alive to a depth of only half or three-quarters of an inch, and the huge *Porites* to a depth of less than a quarter of an inch: that is, only a thin exterior portion of the mass is really living.

Besides corals and shells, there are also some kinds of calcareous vegetation, called *Nullipores*, both branching and incrusting in form, which add to the accumulation. They grow well over the edge of the reef, in the face of the breakers, and attain considerable thickness. Even the delicate branching kinds sometimes made thick beds, as observed by Agassiz in the Florida seas. Bryozoans add a little to the material, occasionally making large massive corals. In Paleozoic time, both branching and massive kinds contributed largely to limestone formations.

Action of the Waves. — The waves, especially in their heavier movements, sweeping over the coral plantations, may be as destructive as winds over forests. They tear up the corals, and, by incessant trituration, reduce the fragments to a great extent to sand; and the debris thus made and ever making is scattered over the bottom, or piled upon the coast by the tide, or swept over the lower parts of the reef into the lagoon. The corals keep growing; and this sand and the fragments go on accumulating: the consolidation of the material thus accumulated makes the ordinary reef-rock. Thus, by the help of the waves, a solid reef-structure is formed from the sparsely-growing corals.

Where the corals are protected from the waves, they grow up bodily to the surface, and make a weak, open structure, instead of the solid reef-rock; or, if it be a closely-branching species, so as to be firm, it still wants the compactness of the reef that has been formed amid the waves.

History of the emerging Atoll. — The growing corals and the accumulating debris reach, at last, low-tide level. The waves continue to pile up on the reef the sand and pebbles and broken masses of coral, — some of the masses even two or three hundred cubic feet in size, — and a field of rough rocks begins to appear above the waves. Next, a beach is completed; and the sands, now mostly above the salt water, are planted by the waves with seeds; and trailing shrubs spring up: afterward, as the soil deepens, palms and other trees rise into forests; and the atoll comes forth finished.

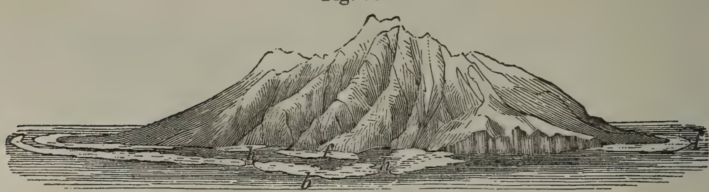
The windward side of such islands is the highest, because here the winds and waves act most powerfully; and, where the leeward side of one part of the year is the windward of another, there may not be much difference between the two. The water that is driven by the winds or tides over the reef, into the lagoon, tends, by its escape, to keep one or more passages open, which, when sufficiently deep, make entrances for shipping.

2. Coral Reefs.

The coral reefs around other lands or islands rest on the bottom along the shores. They are either *fringing* or *barrier* reefs, according to their position. *Fringing* reefs are attached directly to the shore, while *barrier* reefs, like artificial moles, are separated from the shore by a channel of water.

Fig. 964 represents an island with a fringing reef (f) a barrier reef (b), and an intervening channel. Just to the right of the middle, the reef is wanting, because of the depth of water; and, farther to the right, there is only a fringing reef. Fig. 966 is a map of an island

Fig. 964.



View of a high island with barrier and fringing reefs.

with a fringing reef; and Figs. 967–969, others, with barrier reefs. At two points through the barrier reef, in Fig. 964, there are openings to harbors (h). Such harbors are common, and generally excellent. The channels uniting them around an island are sometimes deep enough for ship navigation, and occasionally, as off eastern Australia, fifty or sixty miles wide. On the other hand, they may be too shallow for boats; in which case, the barrier-reefs coalesce with the fringing reefs.

The barrier sometimes becomes wooded for long distances, like the reef of an atoll; but the wooded portion, when there is any at all, is usually confined to a few islets.

The barrier and fringing reefs are formed precisely like the atoll reefs; and special explanations are needless.

The absence of reefs from parts of coasts of islands, within coral-reef seas, is due to several causes: (1) to the depth of water, for corals fail if the depth exceeds one hundred feet; (2) to fresh-water streams, especially if bringing in detritus, which destroys the living corals; as such fresh waters flow over the surface of the salt, they do not prevent the corals from growing below, unless impure with detritus; (3) tidal and other currents, which keep passages open, by means of the detritus they often bear along their course. These are the principal causes that prevent the harbors from becoming filled with corals and thereby destroyed.

The growth of the different parts of a reef, or its prolongation in one direction or another, depends much on the tidal and other currents that sweep through the channel or by the side of the island. As in the case of silt along other sea-shores, the coral detritus made by the waves is distributed by these currents: and hence the increase of a reef is not dependent solely on the number of growing corals over its surface, or their kinds.

Breadth of Reefs. — The reefs adjoining lands have sometimes great width. On the north side of the Feejees, the reef-grounds are five to fifteen miles in width. In New Caledonia, they extend one hundred and fifty miles north of the island, and fifty south, making a total length of four hundred miles. Along northeastern Australia, they stretch on, although with many interruptions, for one thousand miles, and often at a distance, as just stated, of fifty or sixty miles from the coast, with a depth between of fifty or sixty fathoms. But the reefs, as they appear at the surface, even over the widest reef-grounds, are in patches, seldom over a mile or two broad. The patches of a single reef-ground are, however, connected by the coral basement beneath them, which is struck, in sounding, at a depth usually of ten to forty or fifty feet.

The transition in the inner channels, from a bottom of coral detritus to one of common mud or earth, derived from the hills of the encircled island, is often very abrupt. Streams from the land bring in this mud, and distribute it according to their courses through the channels.

Thickness of Reefs. — The thickness of a coral formation is often very great. From soundings within a short distance of coral islands, it is certain that this thickness is in some cases thousands of feet. Within three-quarters of a mile of Clermont Tonnerre, in a sounding made by Hudson, the lead struck and brought up an instant at two thousand feet, and then fell off and ran out to three thousand six hundred feet, without finding bottom; and seven miles from the same island, no bottom was found at six thousand feet.

The barrier reefs remote from an island must stand in deep water

Supposing the slope of the bottom at the Gambier Islands only five degrees, we find, by a simple calculation, that the reef has a thickness of twelve hundred feet. In a similar manner, we learn that it must be at least two hundred and fifty feet at Tahiti, and two or three thousand at the Feejees.

3. Origin of the Forms of Reefs, — the Atoll and the distant Barrier.

The origin of the atoll form of reefs was first explained by Darwin. According to the theory, each atoll began as a fringing reef, around an ordinary island; and the slow sinking of the island till it disappeared, while the reef continued to grow upward, left the reef at the surface, a ring of coral around a lake.

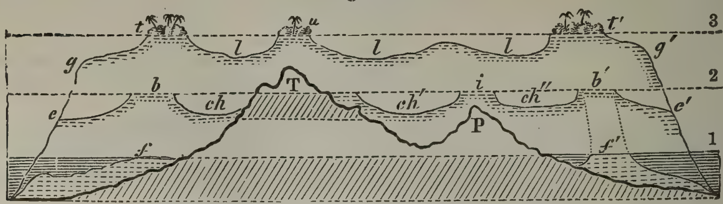
The proofs are —

1. As reef-forming corals grow only within depths not greater than one hundred feet, the bottom on which they began must have been no deeper than this; and as such a shallow depth is to be found, with rare exceptions, only around the shores of lands or islands, the reef formed would be at first nothing but a fringing reef.

2. A fringing reef being the first step in coral formations, slow subsidence would make it a *barrier*-reef.

In Fig. 965, a section of a high island with its coral reefs is represented, the horizontal line 1 being the level of the sea, f a section of the fringing reef on the left, and f' of that on the right. The growing reef depends for its upward progress on the growth of the coral, and on the waves. The waves act only on the outer margin of a reef, while the dirt and fresh water of the land directly retard the

Fig. 965.



Section of an island bordered by a coral reef, to illustrate the effects of a subsidence.

inner part. Hence the outer portion would increase the most rapidly, and would retain itself at the surface, during a slow subsidence that would submerge the inner portion. The first step, therefore, in such a subsidence, is to change a fringing reef into a barrier-reef (or one with a channel of water separating it from the shore). The continued subsidence would widen and deepen this channel; then, as the island

began to disappear, the channel would become a lake, with a few peaks above its surface; then, a single peak of the old land might be all that was left; and finally this would disappear, and the coral reef come forth an atoll, with its lagoon complete.

Referring again to the figure: if, in the subsidence, the horizontal line 2 become the sea-level, the former fringing reef f is now at b, a barrier reef, and f' is at b', and ch, ch', ch'' are sections of parts of the broad channel or area of water within; over one of the peaks, P, of the sinking island, there is an islet of coral, i: when the subsidence has made the horizontal line 3 the sea-level, the former land has wholly disappeared, leaving the barrier-reef, t, t', alone at the surface, around a lagoon, $l\ l\ l$, with an islet, u, over the peak T, which was the last point to disappear.

These steps are well illustrated at the Feejees. The island Goro (Fig. 966) has a fringing reef; Angau (Fig. 967), a barrier; Exploring Isles (Fig. 968), a very distant barrier, with a few islets; Numuku (Fig. 969), a lake with a single rock. The disappearance of this last rock would make the island a true atoll.

Figs. 966–969.

Islands of the Feejee group: Fig. 966, Goro; 967, Angau; 968, Exploring Isles; 969, Numuku.

Whenever the subsidence ceases, the waves build up the land above the reach of the tides; seeds take root; and the reef becomes covered with foliage.

The atoll Menchikoff (Fig. 962) was evidently formed, as explained by Darwin, about a high island, consisting of two distinct ridges or clusters of summits, like Maui and Oahu in the Hawaian group.

If the subsidence be still continued, after the formation of the atoll, the coral island will gradually diminish its diameter, until finally it may be reduced to a mere sand-bank, or become submerged in the depths of the ocean.

The rate of subsidence required to produce these results cannot exceed the rate of upward increase of the reef-ground. On page 591, some estimates are given with regard to the exceeding slowness of the movement.[1]

As coral debris is distributed, by the waves and currents, according to the same laws that govern the deposition of silt on sea-coasts, it does not necessarily follow that the existence of a reef in the form of a barrier is evidence of subsidence in that region. On page 670, the existence of sand-barriers of similar position is shown to be a com-

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[1] For further information on the subject of Corals and Coral Islands, the reader may refer to the author's *Exploring Expedition Report on Zoophytes*, 740 pp., 4to, and 61 plates in folio, 1846, and to his recent work on *Corals and Coral Islands*, 398 pp., 8vo, 1872; also to Darwin on the *Structure and Distribution of Coral Reefs*, 214 pp., 8vo, with maps and illustrations, London, 1842.

mon feature of coasts like that of eastern North America. In the cases of the barriers about the islands of the Pacific, however, there is no question on this point. Such barriers do not form about so small islands. Moreover, the great distances of the reefs from the shores, in many cases, and the existence of islands representing all the steps between that with a fringing reef and the true atoll, leave no room for doubt. The remoteness of the Australian barrier from the continent, and the great depth of water in the wide channel, show that this reef is unquestionable proof of a subsidence, — though it is not easy to determine the amount. Along the shores of continents, the question whether a barrier coral reef is evidence of subsidence or not must be decided by the facts connected with each special case.

Recapitulation. — The following are some of the points, connected with the formation of limestone strata, illustrated by coral reefs: —

1. The narrow geographical limits of coral-reef rocks at the *present* time, owing to the existing zones of oceanic temperature.

2. The narrow limit in depth of the reef-making corals, — this depth not exceeding one hundred feet.

3. The promiscuous growth of the corals over the reef-grounds.

4. The perfect compactness and freedom from fossils of a large proportion of the coral rock, although made within a few hundred feet of living corals and shells; the oölitic structure of part of this compact kind; while a variety made of broken corals cemented together is common on the seaward side of a reef, and another, made of standing corals with the interstices filled, forms where there is shelter from the ocean's waves.

5. The aid of the waves of the ocean necessary, for making a solid limestone out of corals or ordinary marine shells.

6. The great extent and thickness of single reefs.

7. The action of tidal currents and those arising from the piling in of the waves during stormy weather, in keeping open channels and harbors, and determining the distribution of the coral detritus.

8. The close proximity, along shores bordered by barrier-reefs, of deposits of coral material and deposits of river or ordinary shore detritus.

9. An exceedingly slow subsidence, in progress during the growth of the corals, the cause of the change of a fringing reef into a barrier, and later into an atoll.

10. The necessity of this subsidence, for giving great thickness to such limestones.

The making of limestones from shells or crinoidal remains is similar to that from corals, the waves wearing them or part of them to sand or mud, and then consolidation taking place. The rate of formation of limestones from shells is slower than that of Coral or Crinoidal limestones, since Mollusks produce in their calcareous secretions much less carbonate of lime in proportion to their bulk.

II. COHESIVE AND CAPILLARY ATTRACTION; GRAVITATION.

1. Cohesion; Crystallization. — The power of cohesion acting in solidification, and that in crystallization, appear to be identical. Steel, bar-iron, marble, granite, are crystallized in their intimate structure; and they show it in the angular grains which make up the mass, and which may be observed on a surface of fracture.

Crystallization is exhibited (1) in the angular solids it produces, called crystals, and (2) in cleavage. Some of the forms of crystals are illustrated in the early pages of this work (pp. 53–59), and cleavage also has been explained (p. 53).

(1.) *Texture of Rocks.* — From cleavage in minerals, comes the angular form of the grains in a crystalline rock. The grains are coarser the slower the crystallization, or, in other words, the slower the rate of cooling during the crystallization, as already explained (p. 64); and with rapid cooling they sometimes disappear altogether, and the material comes out glass instead of stone.

Perfect crystals are not generally found in the rocky mass because the grains crowd on one another. The mineral in the mass that solidifies first, or takes regular crystalline forms most readily, may make crystals in the midst of the rest, and so a porphyry may result, or a schist full of garnets, or a granular limestone full of tremolite. In porphyritic rocks, the feldspar crystals are sometimes a less fusible species than the feldspar of the base, but sometimes they are the same species of feldspar. Crystals that are perfect in their terminations are most common in the cavities of rocks, where they have space to expand without interference.

To produce, or alter in texture a crystalline-granular rock, heat short of fusion is generally sufficient. In tempering steel, sudden cooling produces a fine grain, and slow, a coarse, the crystalline texture of the *solid* bar undergoing a complete change, and one in which every molecule participates.

(2.) *Fissile and Massive Structure.* — The eminently easy cleavage of *mica* generally gives a very fissile structure to the rocks consisting largely of it. This is uniformly true where the other mineral present is mainly quartz in grains, for quartz has no cleavage of its own to contest with that of the mica; yet it sometimes fails when the quartz is greatly in excess. *Hornblende* is another cleavable mineral characterizing fissile rocks. But when crystallizing freely at a high temperature, its grains become interlocked in all kinds of positions, and hence hornblende rocks derived from igneous fusion, and a large part of those that

are metamorphic, are massive. *Pyroxene*, for the latter reason, seldom makes any but massive rocks, whether of igneous or metamorphic origin. *Feldspar* also usually makes massive rocks under both conditions; and often in spite of the presence of much mica. Quartz forms massive rocks except when determined otherwise through its sedimentary origin; and the thin bedding of quartzose sedimentary beds is often wholly obliterated during metamorphism. Massive structure is, therefore, not necessarily evidence of igneous origin. Slaty rocks, like roofing slate, often owe their fissile structure to pressure. (See p. 794 for remarks on this subject, and on the schistose structure of mica schist, gneiss, and related rocks, called often *foliation.*)

(3.) *Concretionary Structure.* — Examples of concretionary forms are given on pages 85–88. There is a general tendency in matter, when solidifying, to concrete around centres. These centres may be determined (1) by foreign substances which act as nuclei, or (2) by the circumstances of solidification, which, according to a general law, favor a commencement of the process at certain points in the mass, assumed at the time. As the solidifying condition is just being reached, instead of the whole simultaneously concreting, the process generally begins at points through the mass; and these points are the centres of the concretions into which the mass solidifies.

The concretions in the same mass are usually of nearly equal size: hence, (3) the points at which solidification in any special case begins are usually nearly equidistant.

Iron-stone and calcareous concretions in beds of rock are examples in which the concreting is due to a mineral solution in the stratum of clay or sand. A solution containing silica may make siliceous concretions: so also a calcareous or a ferruginous solution may be the concreting agent. The silica may come from infusorial remains in the bed, and the calcareous materials of the solution from calcareous grains, and each be taken into solution by permeating waters.

A mineral solution (or any liquid) naturally spreads equally in all directions through a sandy or earthy stratum, and makes, therefore, spherical concretions; but, in a clayey rock, it spreads laterally most rapidly, and so leads to flattened concretions, the diameters varying with the rate of spreading in the two directions.

In a concretionary mass, the drying of the *exterior*, by absorption around, may lead to its concreting first. It then forms a shell, with a wet, unsolidified interior. The interior, may then dry, contract, and become cracked, as in Figs. 72, 73; or, it may undergo no solidification, and remain as loose earth; or, it may solidify by the concreting process, form a ball within a shell, with loose earth between. The conditions giving rise to hollow balls among spheroidal concretions

would produce rings among flattened concretions, or in clayey layers. The solidification commences first at the circumference, and then the circle thus begun acts as a nucleus about which concreting is continued.

The concentric coats in many concretions are due to an intermittent action in the concreting process. If a drop of a weak solution of sugar dry upon a slab of stone in the air, concentric rings result. The outer edge of the circular spot dries most rapidly; and, when solidification begins along it, the liquid inside for a limited distance is drawn to the concreting circle, exhausting the sugar for that distance inward; then the spot of dissolved sugar, thus made smaller, concretes again at its outer edge, and forms in the end a new circle; and so it goes on until all is evaporated. A concentric arrangement of colors and of layers is often thus produced in ferruginous concretions, the outer shell first drying and concreting, and afterward successive concentric shells, to the centre.

(4.) *Resistance to Fracture.* — Rocks owe their power to resist fracture under pressure, *first*, to *the nature of the grains:* their hardness, cleavability, shape and arrangement, size if cleavable; and *secondly*, to *the nature of the mass:* the strength of cohesion in it, closeness of texture, degree of schistosity, and degree of elasticity. The trials of General Gilmore with American rocks showed that trap (doleryte), although not the hardest, is one of the firmest of rocks. He found the weight required, per square inch, to crush New Jersey *trap*, 20,750 to 24,040 lbs.; for *granite* of Westerly, R. I., 17,750 lbs.; of Richmond, Va., 21,250; of Fox Island, Me., 15,062; for *syenyte* of Quincy, Mass., 17,750; for *sandstone* of Portland, Ct., 6,950; of Belleville, N. J., 10,250; of Berea, O., 8,300; of Amherst, O., 6,850; of Dorchester, N. B. (the olive green rock), 9,150; of Medina, N. Y., 17,250; for *limestone* (black) of Glens Falls, N. Y., 11,475; of Joliet, Ill., 11,250; of Caen, France, 3,650; for *marble* of Tuckahoe, N. Y., 12,950; of Dorset, Vt., 7,612; statuary, of Carrara, Italy, 9.723. Gen. Franklin found the weight required to crush the marble of Pittsford, Vt., with two specimens, 9,028 and 12,239 lbs.

P. Michelot obtained for the crushing-weight of basalt of Estelle, France, 26,830 lbs.; of good granite of France, 14,330 to 21,500; of the best compact limestones, 12,900 lbs.; of the best marbles, 7,160 to 10,000 lbs.; of trachytes, 5,170 to 13,600.

Wet, absorbent rocks, crush much more easily than dry, wet chalk requiring but one third that of dry. This easy slipping of the grains is a mechanical effect in part, but is often owing also to the water dissolving a slight portion of the material.

2. Capillary Attraction. — The process resulting in concentric coats, described in a paragraph above, is due partly, as is seen, to cap-

illary attraction. In the drying of the soil during dry seasons, the loss of moisture at the surface is attended by a rise of moisture, through capillary attraction, from the deeper part of the soil; and thus vegetation is often sustained through a long drought. If the waters below contain soluble saline substances, these salts are brought to the surface, there to crystallize, and make what are called efflorescent crusts; and, in a dry climate, like that of Nevada and many other regions, such a crust may become quite thick, or in a lake basin, make the waters saline. The saline substances referred to include common salt, carbonate of soda, sulphate of soda, alum, sulphate of magnesia, borax, gypsum, carbonate of soda-and-lime (gay-lussite), etc. Many remarkable facts connected with Nevada deposits are described by King in his Geological Report (1878).

When infiltrating waters cause the superficial decomposition of a rock, the drying of the surface tends to bring whatever is dissolved to the surface, and thus produce a film over it. Limestone, if it contains any iron, is sometimes covered in this way with a brownish-yellow film, or, if manganese, a black film of the oxyd of manganese.

3. Gravitation. — In the case of slopes made by the fall of dry sand or stones, gravitation and friction are the chief causes of the positions assumed. Such an accumulation at the foot of a bluff is called a *talus;* and those of volcanic cinders, about a vent of eruption, make a volcanic cone. A talus of dry sand may have an angle of 32° to 35°, it slipping easily if at a higher angle; one of angular stones, such as forms at the base of a bluff of trap, 38° to 40°; volcanic cinders about 40°. Where abundant waters from rains accompany the fall, the slope, if the material is earth or sand, will be diminished to different angles, from 30° to 15°, according to the amount of water; and, with a very free supply, to a much smaller angle.

Gravity or pressure often causes compression and displacements of soft beds; and sometimes, when hard portions are inclosed in the soft, the latter are pushed down along side of the former and make the vertical groovings called *Stylolites.* (Marsh.)

III. THE ATMOSPHERE.

The atmosphere performs geological work mechanically, (1) by rending or abrading, and (2) by transportation.

The force of the wind, measured by the pressure on a square foot, increases with the square of the velocity. At 5 miles an hour, the pressure is about 2 ounces to the square foot; at 10 miles, which is that of a light breeze, 8 ounces; at 20 miles, a good steady breeze, 2 pounds; at 40 miles, a strong gale, 8 pounds; at 60 miles, 18 pounds; at 100

miles, 50 pounds. But the actual force exerted depends largely on the form of the surface struck. This is well shown in the anemometer made of hemispherical cups: the difference between the pressure on the concave and convex sides being such that the cups move one third as fast as the wind, whereas with flat disks there would be no motion. A velocity of 186 miles an hour (or 170 pounds to the square foot) has been registered by the anemometer.

1. Rending and Abrasion.

1. *By direct impulse.* — The rending effects of hurricanes need no special illustration. The effects are a consequence of the direct impulse of the air, and are especially destructive when the moving air is brought to bear in a large volume through converging surfaces in surrounding objects, or in the object itself. The adhesion of ordinary hardened mud may not be overcome by a gale that prostrates a forest, destroys houses, or throws over lofty piles or columns of rock which degradation from any cause had left standing.

2. *Through the Material transported.* — By means of the sand which winds often carry, a large amount of wear is accomplished in arid regions. Attention was first called to this point by W. P. Blake, who described the granite of the Pass of San Bernardino, California, as scratched like rocks of glacier regions, even the quartz being polished and the garnets left projecting on pedicels of feldspar; and the limestone as eroded and channeled as if by dissolving waters. Many of the bluffs, needles, and towers of soft sandstone characterizing the scenery in different parts of the Rocky Mountain region have been more or less shaped by this means. It was observed long ago that the glass of windows on Cape Cod had been ground and bored through, by the wind-driven sands. A blast of sand propelled by steam is now employed (after Nature's suggestion) in grinding and carving glass, gems, and even granite. Glass covered by lace-work, or by paper having open patterns cut in it, is rapidly worn where its surface is exposed, while the lace or paper, owing to its yielding before the sand, shows scarcely any effect of the blast. Large cornices and mouldings of granite are shaped by a blast of steam and sand.

2. Transportation.

The streets of most cities, and the roads of the country, in a dry summer day, as well as deserts and sea-coasts, afford examples of the drift of *dust* or *sand* by the winds; and almost all regions, of the drifting to long distances of leaves and forest debris, or of insects and other lighter kinds of life within reach of the swiftly moving air.

1. *Drift-sand Accumulations.* — The amount of sand transportation is greatest, other things equal, where there is no covering of vegetation to keep down the sands; and the deposits made are most extensive in the direction of the prevailing currents. The interior of continents are by nature mostly free from drift sands, owing to the wide spread prairies and forests, excepting certain arid or desert regions, and small local areas. Windward sea-coasts are the localities where drifting goes forward most rapidly. The seashore is commonly a narrow strip of incoherent sands, and this narrow strip is the margin of a broad region of loose sands extending out in the shallow waters. The winds, blowing across the beach and the sand-laden breakers, take up the sand and carry it beyond the beach, where it forms, nearly parallel with the coast, what are called sand-drift ridges or hills. They are made especially where the sands are almost purely siliceous, and hence are inadhesive, and little fit for any kind of vegetation. They have often a height of thirty feet, and sometimes of a hundred, as on the east side of Lake Michigan. They take their greatest height on projecting coasts that receive the winds from different directions.

On the south side of Long Island such ridges extend along for a hundred miles, and they vary in height from 5 to 30 feet. The coast of New Jersey, down to the Chesapeake, and others farther south, are similarly fronted by sand-hills. In Norfolk, England, between Hunstanton and Weybourne, they are 50 to 60 feet high. On the north side of Oahu, one of the Hawaiian Islands, they are 30 feet high; and on the coral islands of the Pacific the windward points sometimes receive thus a height of 20 or 30 feet, while the leeward side may have not even a beach. They form along the shores also of large lakes. On the east side of Lake Michigan, according to A. Winchell, the sand-hills reach a height of 100 to 200 feet; they are 215 feet high at Grand Haven, and 30 to 93 near New Buffalo. Lyell speaks of drift-hills on the north coast of Cornwall, several hundred feet above the level of the sea.

These accumulations have the peculiar kind of quaquaversal stratification described and figured on page 82 (Fig. 61 *d*). Curving planes in the lamination show former shapes of the hill; and abrupt changes of direction, indicate that the growing hill was cut partly down or through by storms, and was again and again completed after the disasters. The forms of snow-drifts are a good study with reference to the natural forms of sand-drifts.

The old sand-hills on northern Oahu, made of coral sand, have become consolidated; and sections of them exhibit well, on some of their sides, this style of lamination. The Pictured Rocks of Lake Superior at some places have the same character, and evince that the beds are in part drift-sand accumulations.

Such seashore driftings are a means of recovering lands from the sea. The sea first makes the sand-flats or beaches, and then the winds do the rest. Lyell observes that, at Yarmouth, England, thousands of acres of land now under cultivation have been thus gained from a former estuary.

The drifting of dust by winds is remarkably exemplified also in the records of the transportation of volcanic ashes. In 1812, such ashes were carried from St. Vincent to Barbadoes, 60 to 70 miles; and in 1835, from the volcano of Coseguina in Guatemala to Jamaica, a distance of 800 miles. The ocean's bed must have received in past times very large contributions from its many volcanic islands.

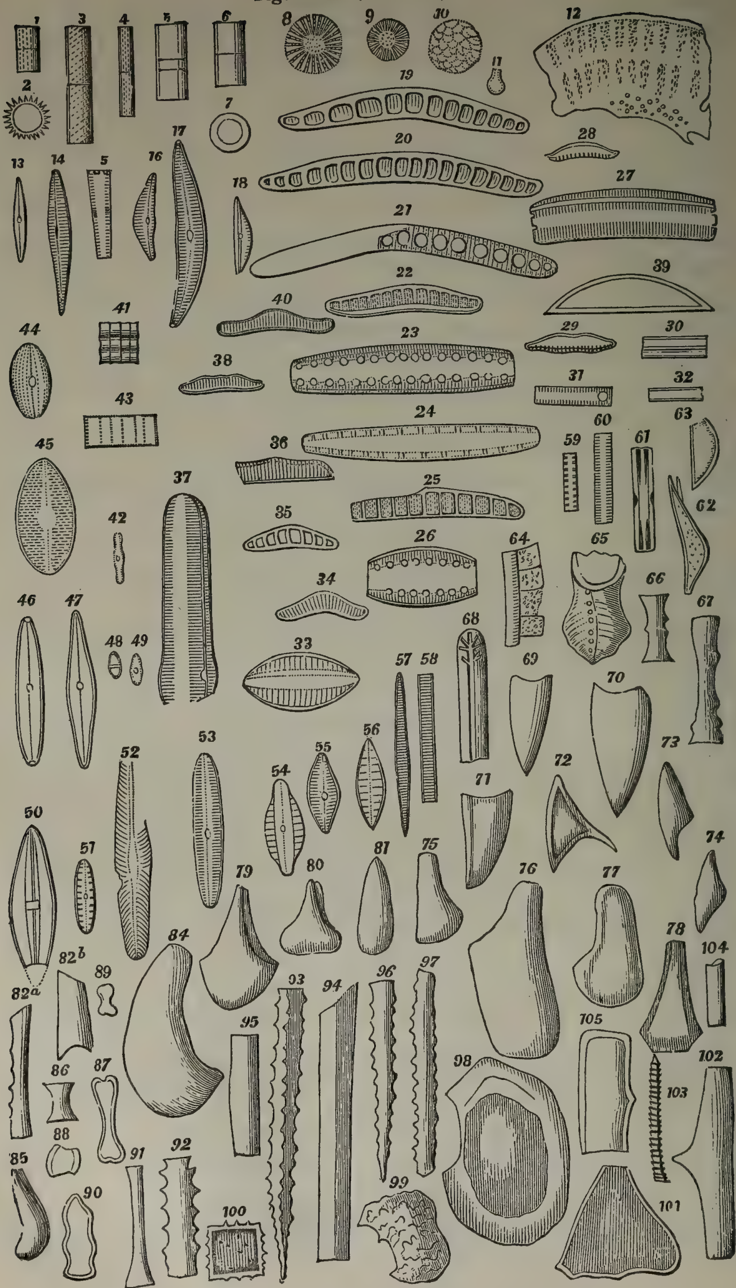
2. *Encroachments of Drift-sand; Dunes.* — Dunes are regions of loose and moving drift-sand near the sea. They often travel inland, through the agency of the winds, and thus encroach on cultivated fields, forests, and villages. Prof. Winchell states that on Lake Michigan the sands are continually shifting with the winds; and at Grand Haven and Sleeping Bear, the forest has become submerged, and "presents the singular spectacle of withered tree-tops projecting a few feet above a waste of sands." The land at this place is extending *lakeward*, through the wear and contributions of the arenaceous shore rocks. In Norfolk, England, the drift-sands have buried farms and houses. They reach but a few miles from the coast line; but here the coast-line is moving landward through eroding waves. By such means, not only bones, shells, tree-trunks, become the fossils of sand heaps, but, in the existing age, even man, his houses, temples, and cities.

3. *Transportation of Living Species, or their Relics.* — A tornado that becomes a "water-spout" over a large river or lake, carrying up at its centre great quantities of water, will take up also the ova and smaller life of the waters, and transfer them to other places, and may thus contribute new species to distant lakes or rivers. Land birds and insects are sometimes drifted far out to sea, and so reach oceanic islands, and sometimes in the case of birds another continent. Seeds of many kinds go with the winds. A spider of the ballooning kind, *Sarotes venatorius*, has probably traveled around the globe, according to H. C. McCook, crossing oceans and continents, and thus has gained a world-wide distribution. A related species is reported by Darwin as suddenly appearing on the rigging of the *Beagle* sixty miles from the land.

Showers of grayish and reddish dust sometimes fall on vessels in the Atlantic off the African coast, and over southern Europe (producing, when they come down with rain, "blood-rains"), the particles of which, as first shown by Ehrenberg, are largely microscopic organisms. The figures on the adjoining page represent the species from a single shower, near Lyons, on October 17, 1846. The whole amount which fell was estimated by Ehrenberg at 720,000 lbs.; and of this one eighth, or 90,000 lbs., consisted of these organisms.

The species figured by Ehrenberg (*Passat-staub und Blut-regen*, 4to, 1847, and *Amer. J. Sci.*, II. xi. 372), include thirty-nine species of siliceous Diatoms (Figs. 1–65);

Figs. 1–105 (970–1075).



Diatoms and other microscopic organisms of a dust-shower.

twenty-five of what he calls Phytolitharia (Figs. 66–104), besides eight of Rhizopods. The following are the names of the Diatoms.

Figs. 1, 2, *Melosira granulata*; 3, *M. decussata*; 4, *M. Marchica*; 5–7, *M. distans*; 8, 9, *Coscinodiscus atmospherica*; 10, *Coscinodiscus* (?); 11, *Trachelomonas levis*; 12, *Campylodiscus clypeus*; 13–15, *Gomphonema gracile*; 16, 17, *Cocconema cymbiforme*; 18 *Cymbella maculata*; 19, 20, *Epithemia longicornis*; (frustule of *E. Argus*); 21, 22, *E. longicornis*; 23, *E. Argus*; 24, *E. longicornis*; 25, *Eunotia granulata* (?); 26, *E. zebrina* (?); 27, *Himantidium Monodon* (?); 28–32, *Eunotia amphioxys*; 33, 34, *Epithemia gibberula*; 35, *Eunotia zebrina* (?); 36, *E. zygodon* (?); 37, *Epithemia gibba*; 38, *Eunotia tridentula*; 39, *E.* (?) *levis*; 40, *Himantidium arcus*; 41, 42, *Tabellaria*; 43, *Odontidium* (?); 44, *Cocconeïs lineata*; 45, *C. atmospherica*; 46, *Navicula bacillum*; 47, *N. amphioxys*; 48, 49, *N. semen*; 50, *N. serians*; 51, *Pinnularia borealis*; 52, *P. viridula*; 53, *P. viridis*; 54, *Mastogloia* (?); 55, *Pinnularia æqualis* (?); 56, *Surirella craticula* (?); 57, 58, *Synedra ulna*; 59, *Odontidium* (?); 60, *Fragilaria pinnata* (?); 61, *Mastogloia* (?); 62–65, doubtful.

A shower which happened near the Cape Verdes, and has been described by Darwin, had by his estimate a breadth of more than 1,600 miles, — or, according to Tuckey, of 1,800 miles, — and reached 800 or 1,000 miles from the coast of Africa. These numbers give an area of more than a million of square miles.

In 1755, there was a "blood-rain" near Lago Maggiore, in northern Italy, covering about two hundred square leagues, which made an earth-deposit in some places an inch deep; if averaging two lines in depth, the amount for each square mile would equal 2,700 cubic feet. The red color of the "blood-rain" is owing to the presence of some red oxyd of iron.

Ehrenberg enumerates a large number of these showers, citing one of the earliest from Homer's Iliad, and among those whose deposits he examined he distinguished over three hundred species of organisms. The species, so far as ascertained, are not African, and fifteen are South American; but the origin of the dust is yet unknown. The zone in which these showers occur covers southern Europe and northern Africa, with the adjoining portion of the Atlantic, and the corresponding latitudes in western and middle Asia.

IV. WATER.

Water takes the lead among geological agencies, both as regards mechanical and chemical work. It has been, through the ages, the chief instrument in rock-making, in shaping mountains, and excavating valleys, and in recording the progress of the earth in its features and life. It has worked in each of its three states, vapor, water, and ice, and in the passage from one state to another; in all these conditions doing mechanical work, and in those of water and vapor, especially, chemical work. In some of its operations it has had the aid of heat, and these are treated beyond under that head.

An important part of its mechanical work is that of weakening cohesion, or softening rocks, as well as earthy beds, by penetrating them or becoming absorbed by them, as briefly brought out on page 629. By this quiet process, and the no less quiet chemical methods explained beyond, it has aided much in preparing the way for its three great labors — erosion, transportation, and deposition.

Water, unlike the air, whose currents are the wayward winds, *has an upper surface*, and this gives it a cutting edge for erosion, and a

limiting plane to grade from and toward in all its work. It is thus enabled to make flat plains or terraces of great width along river valleys and seashores, and give horizontality to its deposits.

The subject of WATER is here presented under the heads, —

1. FRESH WATER; including especially Rivers and Lakes.
2. The OCEAN.
3. FROZEN WATER, or Glaciers and Icebergs.
4. WATER AS A CHEMICAL AGENT.

I. FRESH WATER.

A. SUPERFICIAL WATERS: RIVERS.

1. GENERAL OBSERVATIONS ON RIVERS.

1. *Water of Rivers.* — The fresh waters of the land come from the vapors of the atmosphere; and these are largely furnished by the ocean. They rise into the upper regions of the atmosphere and, becoming condensed into drops, descend about the hills and plains, in streamlets that combine into rivers and river-systems.

The area which a river with its tributaries — or a river system (p. 22) — covers is called its *drainage-area;* and the amount of water in a river depends largely (1) on the extent of its drainage-area. The extent of that of the Mississippi is about 1,317,500 square miles; of the St. Lawrence, 298,000; of the Mackenzie River, 442,000; of the Amazon, 2,264,000 (a third part of South America); and of the La Plata, 886,000. North America has one river over 500,000 square miles in drainage area; South America, 2, and Asia, 6; and this large number in Asia is due to the size of the Continent, and the great distance of the eastern and northern mountains ranges from the coast.

The drainage area of the Danube is 234,000 square miles; Volga, 397,000; Rhine, 65,000; Elbe, 42,000; of the Nile, 520,000; of the Obi, in Asia, 925,000; Lena, 594,000; Amur, 583,000; the Yenesei, 785,000; Yang-tze-kiang, in China, 548,000; Hoang-ho, 537,000 (the words *kiang* and *ho* signify *river*); Ganges, 432,000; Indus, 312,000.

But the amount of water in a river obviously depends also on (2) the amount of rain, mist, or snow of the region; (3) its climate, — heat and a dry atmosphere increasing the loss by evaporation; (4) its geological nature, — absorbent and cavernous rocks carrying off much of the water, and metamorphic or crystalline rocks almost none; (5) its physical features, — a flat, open, unwooded country favoring evaporation.

The amount of precipitated moisture is vastly the greatest in the tropics, where evaporation is abundant, and where, if there are high mountains, the contrasts of temperature at hand are extreme. It is

greater also over the parts of continents within a few hundred miles of the oceans than over those more distant, and over high mountains than over the plains, as these are gathering places, owing to their height and coldness. Further, America, considering its extent, is much better supplied than Europe and Africa (p. 44). In the tropics of the Old World the annual amount of precipitation is about 77 inches, while it is 155 inches in South America. In the Eastern United States, it is 40 to 50 inches; but west of the one hundredth meridian, beyond the Mississippi to the Sierra Nevada, it is mostly 12 to 16 inches. The annual amount in Great Britain averages 35 inches; France 20 to 21; the country, farther from the coast, in Central Germany and Russia, only 15 to 20 inches; but about the Alps, it is mostly 35 to 50 inches.

Of the water precipitated, the rivers seldom carry off one half, except in regions of metamorphic rocks. In most parts of temperate latitudes the amount is a third to two fifths of what falls; the rest disappears: (1) by evaporation; (2) by becoming absorbed or subterranean; and (3) by being taken up by plants, animals, and mineral oxidation. In warm latitudes, the amount is less, and may be under one tenth. The annual discharge of the Mississippi River averages nineteen and a half trillions (19,500,000,000,000) of cubic feet, varying from eleven trillions in dry years to twenty-seven trillions in wet years. This amount is about *one quarter* of that furnished by the rains.

The Amazon, in the hot tropics, with a drainage area not twice as large, carries to the sea *five times* as much water as the Mississippi.

The mean annual discharge of the Missouri River is about three and three-quarter trillions, or *fifteen hundredths* of the amount of the rains over the region. The corresponding amount for the Ohio is five trillions, which is *one quarter* the amount of rain. (Humphreys & Abbott.) The Ganges carries down about four and a half trillions annually, and the Nile three and one fifth trillions. The rivers of England and Wales carry to the sea 18.3 inches in depth out of an annual fall of about 32 inches.

The distribution of the tributaries of a stream has much to do with the supply of water received, as is illustrated by the Mississippi and Amazon. The former river has its smaller eastern tributaries from regions where the annual precipitation is 35 to 50 inches; but its northern and its far-reaching northwestern and western tributaries come from where only 12 to 20 inches of rain fall in a year; moreover, the flood-seasons for the two sets are nearly the same, that is, in the spring and autumn. On the contrary, the Amazon, whose trunk is near the equator, besides being in one of the rainiest parts of the globe, has large tributaries, descending from regions north of the equator, which are flooded from the great rains during the rainy sea-

son of the northern hemisphere, and still larger tributaries from the country south of the equator, bringing in floods from the rainy season of the southern hemisphere. Thus it is with many rivers, their wide-spread arms taking advantage of the difference in the seasons or climate of the distant countries whence they get supplies.

Rivers that rise in snowy heights, like the Rhine, Rhone, and Danube, have their channels kept well filled through the summer, the time of drought, because that is the melting-time of the snows.

Lakes are the relatively still-water portions of rivers. But they are also reservoirs that store away water in the time of floods, and let them out, gradually, after the floods have passed; and these floods often make temporary lakes along a river course that prolong much the period of high water. The quiet at the "Whirlpool," in the rapids below the Falls of Niagara, is accounted for by the great increase in the depth of the passage and the abrupt expansion in breadth.

Forest regions, by keeping the soil beneath charged with moisture, tend, like lakes, to make gradual and constant the supply of water to rivers, and give uniformity to the flow; and hence, when forests are cut away, the rains reach speedily the streams, making them liable to alternate periods of wasteful violence and worthless feebleness. The cutting away of the forests has led, in the French Alps (Dauphiny), to uncontrollable erosion, despoiled fields, and an impoverishment of the people; and, in America, to annual seasons of dry mill-ponds, an immense sacrifice of available water-power, and the desertion of many a mill-site.

2. *Amount of Pitch or Descent in Rivers.* — The average descent of large rivers, excluding regions of cascades, seldom exceeds twelve inches to a mile, and is sometimes but one third this amount.

The pitch of the Mississippi, from Memphis down (855 m.) is only 4.82 inches at low water; from Cairo, at mouth of Ohio River (1,088 m.), 6.94 inches; and above the Missouri, from its source, only $11\frac{3}{4}$ inches. The Missouri, from its highest source (2,908 m.) descends about 6,800 feet, or 28 inches a mile; but from Fort Benton to St. Joseph (2,160 m.), about $11\frac{1}{2}$ inches; and below St. Joseph to the mouth (484 m.) $9\frac{1}{4}$. (From Humphreys and Abbot.) The average pitch of the Amazon is little more than 6 inches a mile; of the Lower Nile, not 7; of the Lower Ganges, about 4. The Rhone is remarkable for its great pitch, it being 80 inches per mile from Geneva to Lyons, and 32 inches below Lyons.

During high floods the course of a river is shortened, because the minor bends are obliterated by the overflow, and where the channel is broad and open, the pitch is commonly increased in amount and uni-

formity. Narrows between rocky bluffs act like a dam, and diminish the pitch above them, often spreading the waters into lakes, while they increase the pitch below. At such narrows, floating ice often makes obstructions in the spring, which increase greatly the height of the waters. A dam higher up the stream, that obstructs or holds back the ice during its break-up, may save large areas from the flooding effect of the narrows. Narrows are sometimes created along streams by encroaching human "improvements;" but such a narrowing of a river's natural flood-grounds may be easily carried so far as to be a sure source of disasters.

3. *Energy or working-power of Rivers.* — The energy or working-power of any body of water — say a lake — equals the product of the weight of the water in pounds (W) into its height (h) above the sea-level, that is, into the vertical distance which it would have to descend to reach the level of the sea. The expression for its value in foot-pounds is Wh. This energy exists in the water solely in virtue of its *position*, just as potential energy, or power of doing mechanical work, exists in the weights of a clock when raised to their highest point. The energy potentially present in a lake a fourth of a square mile in surface, 10 feet in average depth, and 400 feet above the sea-level, is 1,742,400,000,000 foot-pounds; — a power sufficient, could it be expended without loss, to raise a mass of stone weighing about 87,000 tons to the top of a mountain 10,000 feet high.

If now the water of this lake were allowed to flow by a continuous gradual slope down to the sea, and if it met with no loss from evaporation, or from resistance of any kind (such as friction, etc.), its velocity would increase regularly according to the well-known law of falling bodies; and, in this increase of rate, it would be constantly accumulating *energy of motion*, which would be the exact equivalent of the energy of position it was losing; and when it reached the lower level its velocity would be 160 feet per second (about 109 miles an hour). Its energy would have thus been entirely transformed from *energy of position* into *energy of motion*, and into an amount capable of doing work equal to that above stated. In the case of falling bodies the relation between the vertical distance fallen through (h) and the acquired velocity (v) is expressed by the formula $h = \frac{v^2}{2g}$, g being the force of gravity, usually taken at 32.2 (it is 32.165 at New York city); so, the energy of the moving body of water may be obtained from the formula $\frac{Wv^2}{2g}$.

In actual experience, the theoretical result can not be realized; on

the contrary, the velocity of a stream does not increase uniformly as it descends, and when it reaches the sea, whatever the elevation at first, its velocity is in most cases nearly zero. This is owing to the fact that its energy, instead of being stored up, is being expended against the various resistances encountered, that is: —

(1.) In overcoming friction between (*a*) the molecules of the water itself; (*b*) the water and the bed of the stream; (*c*) the surface of the water and the atmosphere.

(2.) In impact, or blows against the rocks or earthy material of the bed and banks of the stream; and in pushing sand or gravel along the bed.

(3.) In transporting earth, sand, or stones, held in suspension in the water.

(4.) In overcoming the friction between the transported particles and the bed of the stream, and the friction between the particles themselves; and also the loss from eddies made by the character or form of the bed or otherwise.

By these means the energy is so far used up, that no accumulation can take place except on portions of a stream where the pitch is uniform and considerable, and the bed is hard and smooth. In a waterfall accumulation goes on during the descent; but the whole energy of the stream is lost in the stroke of the water at the bottom of the fall, where it is converted into heat, — a fall of 772 feet producing heat enough to raise the temperature of the water 1° F.

Owing to the rapid increase of velocity in the descending water of a waterfall, the stream in a high fall of small volume becomes divided up, the parts running away from one another and finally separating into drops; in which case, owing to the resistance of the air, the velocity, and therefore the energy, is almost wholly dissipated, and the fall becomes a veil of mist, swayed by the winds.

The amount of actual work which a stream is capable of doing at any point in its flow increases with the mass of the water and the square of its mean velocity, its value being given by the formula $\frac{Wv^2}{2g}$ already stated. The greatest velocity will be near the middle of the stream, or as remote as possible from the surfaces of friction; and, owing to the friction with the atmosphere, below the upper surface. The vertical curve of subsurface velocities, according to Humphrey's and Abbot's careful observations on the Mississippi (confirmed by General Ellis's on the Connecticut) is parabolic; the axis, or line of greatest velocity, is about one-tenth of the depth below the surface; and *the velocity at mid-depth* equals almost uniformly 0.955 the mean velocity; a wind up stream depresses it slightly, and one down stream raises it.

Other characteristics of rivers are brought out in the following pages.

2. Mechanical Effects of Rivers.

The mechanical effects of fresh waters are, —

1. Erosion, or wear.
2. Transportation of earth, gravel, stones, etc.
3. Distribution of transported material, and the formation of fragmental deposits.

1. Erosion.

1. *General Statement of the Effects of Erosion.* — The effects of erosion are seen, *first*, in the imprint of the falling rain-drop, — a trifling matter to most eyes, but not so to the geologist; for it remains, among the records of the earliest and latest strata, to show that it rained then as now, and to teach us where the lands at the time lay above the ocean. It is, therefore, a part of the markings in which the geographical history of the globe is registered.

Second. The gathering drops make the rill, and the rill its little furrow; rills combine into rivulets, and rivulets make a gully down the hill-side; rivulets unite to form torrents, and these work with accumulating force, and excavate deep gorges in the declivities. Other torrents form in the same manner about the mountain-ridge, and pursue the same work of erosion, until the slopes are a series of valleys and ridges, and the summit a bold crest, overlooking the eroding waters.

2. *Progress of erosion in the Formation of Valleys or River Courses.* — The mist and rains or snow about the higher parts of mountains are the main source of the water. As the first-made streamlets gather into larger streams, on the descent, and are largest below, there the valley first takes shape.

Fig. 1076.

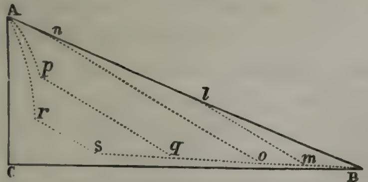
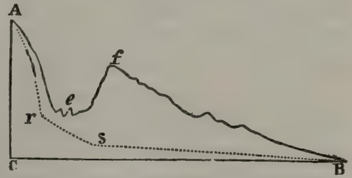


Fig. 1077.



Let $A\ B$ (Fig. 1076) represent a profile of a declivity. As the erosion goes on, a valley is formed along $l\ m$, on the principle just stated, with but little channelling above along $A\ l$. On reaching m, the most of the descent of the declivity is made: the waters from m to B have, therefore, but little eroding power at bottom, and they commence to erode laterally during freshets, undermining the cliffs on either side,

when the rocks admit of it, thus widening the valley and making a "flood-plain," or "bottom-lands," through which the stream when low has its winding channel. With further progress in the erosion, *A n o B* becomes the channel for the stream.

The river, in this state, consists of its *torrent-portion*, *A n o*, and its *river-portion*, *o m* B. Along the former, a transverse section of the valley is approximately V-shaped, and along the latter nearly U-shaped, or else like a V flattened at bottom. The river-portion, *o m B*, usually exhibits, even in its incipient stages, its two prominent elements, — a *river-channel*, occupied by the waters in ordinary seasons, and the *alluvial flat*, or *flood-ground*, which is mostly covered by the higher freshets. The two go together, whenever the course of the stream is not over and between rocks that do not admit of much lateral erosion and the widening thereby of the river-valley.

These steps are illustrated about the volcanic mountains of the Pacific, the more recently extinct of which, like Mount Kea, on Hawaii, have their valleys confined mainly to the lower slopes, while the older mountains are cut through the summit with profound gorges. Mount Loa, which is still in action, has few valleys of erosion in any part, although, like Kea, nearly 14,000 feet in height.

As the waters continue their work of erosion about the summits, where the mists and rains are most abundant and often almost perpetual through the year, the next step is the working down of a precipice under the summit, or toward the top of the declivity, making the course of the waters *A p q B*, and later, *A r s B*. The stream in this state has (1) a *cascade-portion* and (2) a *torrent-portion*, besides (3) its *river-portion*. The precipices thus formed are sometimes thousands of feet in height; and the waters descend them in many thready lines, to unite below in the torrent. The mountain-top is chiseled out, by these means, into a narrow, crest-like ridge or peak. Each separate descending rill frequently makes its own valley-like recess in the side of the precipice; and together they may face it with a series of deep alcoves and projecting buttresses.

The next step in the progressing erosion is the thinning and wearing away of the ridges that intervene between adjoining valleys, in the higher regions where the descending waters are most abundant. By this means two valleys (or more by the wear of more ridges) are often made to have a common head. In Fig. 1077, *A r s B* represents the course of the stream, as in Fig. 1076; and *A e f B* the eroded ridge, which has lost at *e* much of its height. The erosion, continuing its action around the precipitous sides of the united head of the valleys, may widen it into a vast mountain amphitheatre, out of which the stream may pass below, between closely approaching

walls of rock. The island of Tahiti affords grand exhibitions of such gorges, knife-edged ridges, and mountain amphitheatres.[1]

A model of this system of erosion is often admirably worked out in the earthy slopes along a road-side, — the little rill having its cascade-head, then its torrent-channel, and, below, its flat alluvial plain, intersected by the little winding water-channel; some of the ridgelets worn away in their upper parts, until two or more little valleys coalesce; then, at times, the head of the coalesced valleys widened into an amphitheatre, and the walls fluted into a series of alcoves and buttresses.

Through this simple method, erosion by running water, nearly all the valleys of the world have been made.

The flood-grounds widen through encroachments on the hills along the margin of the flood waters. But they may have their limits either side varied by changes of level in the land, subsidences widening them, and elevations narrowing them; or by a change for a long geological period in the amount of water supplied by precipitation, an increase widening them by new encroachments, and a decrease narrowing them, and producing, finally, a new plane at a lower level.

On some large rivers the flood-grounds extend more than fifty miles from the low-water channel. On the Mississippi, abreast of Tennessee, they are in some parts over fifty miles wide; on the Amazon (up which the tides go 400 miles), over a hundred miles; on the Paraguay there are lagoons 300 miles in length.

The *nature of the rocks* causes modifications in the results of erosion. If there are harder beds at intervals, in the course of the stream, or any impediment to even wear, the impediment, by resisting erosion, becomes the head of a waterfall and precipice, whose height increases rapidly from the force of the falling waters, until some other similar impediment below limits the further erosion. Many waterfalls and rapids are thus made in the cascade-portion of a stream; and they are not absent from the river-portion. Another effect of this cause is that the stream is set back for some distance above a waterfall, and has in this part more or less extensive flood-plains.

Fig. 1092 represents some remarkably slender columns of Tertiary sandstone, from the Report of Dr. Hayden for 1873. There are here two layers harder than the rest; and one has been left to make the top of the taller column, while another caps a shorter series. These examples of nature's modeling are very numerous in Colorado, over what has been called Monument Park. The erosion is due to the rains, or the rills they produce, and the latter part to the gentler action of rain-drops, together with the action of the winds and frosts. Lyell has described a remarkable example of erosion by rains, of a thick deposit of reddish indurated mud, containing scattered bowlders, really a

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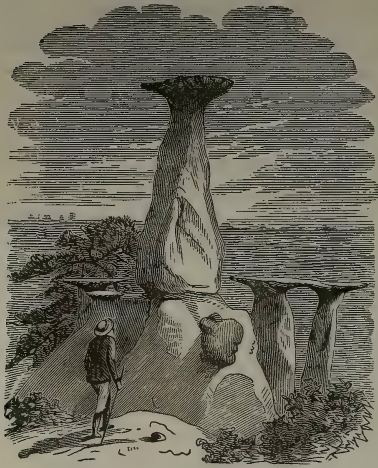
[1] See the Author's *Expl. Exped. Geol. Rep.*, pp. 290, 384, and *Am. J. Sci.*, II. ix. 48 and 289, 1850.

moraine, occurring near Botzen in the Tyrol, in which the result is a region of many hundreds of slender pillars and columns of half consolidated earth, twenty to a hundred feet in height, and each capped with a bowlder, — some of the stones two or three feet in diameter. He gives a view of one such scene in his "Principles," chapter xv.

Fig. 1078.



Erosion, Monument Park, Colorado.

The *positions of the strata* have also great modifying influence. This is especially true when they are *horizontal.* All lateral wear in gorges intersecting horizontal beds, such as takes place with great energy during periods of floods, tends to remove the exposed lower layers, and so undermine those above; and consequently the latter, from time to time, fall, making a vertical or overhanging precipice either side of the stream. The debris made by the fall may be wholly removed by the violent torrent. The excavation in such rocks, unless they are very hard, is carried forward with comparative rapidity; because undermining is facilitated by the bedding of the rock, and because gravity acts so promptly in bringing the dislodged masses within reach of the flowing waters. The river portion of the valley may thus be carried far into the heart of the mountains, and terminate in a great amphitheatre; and although so deep, it will remain a gorge or cañon, owing to the force of the flood waters, until the pitch of the stream has been reduced to a very small amount, and usually until it is less than twelve inches a mile. By such method, gorges with vertical walls hundreds and thousands of feet in elevation, have been excavated by running waters. And when the descent has become gentle, the stream, in these depths, meanders through a ribbon of alluvial land rich in verdure at one season, and in others mostly flooded.

Examples of such valleys occur in all elevated regions of horizontal rocks. The upper part of the Mississippi valley, the Rocky Mountain region, and the plateaus of its western slope, the eastern Alps, and eastern Australia, are full of them. The Cañon of the Colorado, between the meridians of 111° and 115° W. has, for the greater part of 200 miles (as described by Newberry, and since by Powell and others), nearly vertical walls 2,000 to 6,000 feet in height, made of Carboniferous limestone and other Paleozoic rocks, with, in some places, the bottom, and the sides for the lower 500 to 1,000 feet of granite; and

all the tributaries flow in similar profound gorges or chasms. (Fig. 1079, from one of the excellent photographs by the artist of Powell's expedition, is a view of "Marble Cañon" — a part of the Colorado gorge, fifty-five miles long, extending from the mouth of the Paria to the mouth of the Little Colorado. The walls, in the distance, have a height of 3,500 feet. The lofty walls of horizontal strata have in places been chiseled down nearly to a true vertical. On page 792, is a bird's-eye view of part of the Colorado basin.

Fig. 1080 is another view from the same remarkable region, illustrating the mountain-forms produced by water-carving within the

Fig. 1079.

Cañon of the Colorado.

cañon; some of the peaks rise 5,500 feet above the bottom. It is from the Report of Captain C. E. Dutton.

These profound gorges, as explained by Newberry, are due simply to erosion, each stream having made its own channel. The cliffs are so high that in general no undermining can set back the walls far enough to allow of alluvial plains along the bottom, even when the water is not too rapid; and, when a channel is cut in granite, lateral wear is always small.

In the distant part of many similar views, there is a higher level of

rock, — the overlying gypsiferous red sandstone, probably Triassic or Jurassic (p. 407). It is in isolated tables, and in some places in columns, needles, and towers, the greater part of the formation hav-

Fig. 1080.

View of peaks and ridges within the Colorado Cañon, south of the Kaibab Plateau.

ing been swept off by erosion. Still farther to the east, beyond the range of the view, another more elevated level is formed by Cretaceous strata with similar surface-features. All the immense amount of erosion, indicated by these lofty, isolated remnants of strata that once must have made part of a great elevated plateau, may be the work of fresh waters alone.

The facts brought forward show that, to produce a cluster or line of crested mountain heights, with summits thousands of feet above the plain around, it is only necessary that subterranean movements should make a plateau of sufficient extent and elevation. Left exposed to the rains, the carving will be all done in time. The Catskills, as well as many mountain regions of the Rocky Mountain territories, and of other parts of the world, owe their features to the eroding action of running waters. Mountains thus cut into shape by water are sometimes called *mountains of circumdenudation.*

Scotch valleys and mountains gave to Hutton the first right ideas on this subject.

When strata, of like durability, have considerable dip, erosion commonly results in sloping surfaces, unless the rocks are so hard as to keep themselves in projecting ledges. But if there is a stratum of easy removal alternating with others harder, as, for example, a stratum of limestone among other kinds of metamorphic rocks, it is apt to determine erosion, and make a valley, along its course, which will be the course of the strike, and also to make, through consequent undermining, a high, precipitous, and often rocky slope on the side toward which the rocks pitch, and a gradual slope on the other; that is, if the dip is westward, the west side will commonly be the high steep side. This principle is illustrated in many parts of the limestone region of western New England and southeastern New York, where the dip is usually 45° to 70°. Some other points with regard to the forms produced by erosion are illustrated on pages 651, 652.

Many examples are on record of gorges, hundreds of feet deep, cut out of the solid rock by two or three centuries only of work. Lyell mentions the case of the Simeto, in Sicily, which had been dammed up by an eruption of lavas in 1603. In two and a half centuries, it had excavated a channel fifty to several hundred feet deep, and in some parts forty to fifty feet wide, although the rock is a hard solid basalt. He also describes a gorge made in a deep bed of decomposed rock, three and a half miles west of Milledgeville, Ga., that was at first a mud-crack a yard deep in which the rains found a chance to make a rill, but which, in twenty years, was 300 yards long, 20 to 180 feet wide and 55 feet deep; and Liais describes a similar gorge, of twice the length, in Brazil, made in forty years. High floods on streams, with broad alluvial regions, often wear into the earthy banks and commence new bends. or cut off old ones; and, sometimes, where broad plains border the sea, they open for themselves new channels for discharge. The great and turbulent Hoang-

Ho, of China, is noted for its devastations. In 1850 it emptied into the Yellow Sea; now this mouth is dry, and it has a new channel opening to the Gulf of Pechele, nearly 300 miles north of its former outlet, and it departed from the old channel more than this distance from the coast. This is the last of many changes, back and forth, recorded by the Chinese during the past 3,000 years. The changes begin in floods caused by the amount of precipitation in the distant Kuenlun Mountains. Such overflows are destructive to lands and crops that support millions, and often also to human life.

The *windings* of a stream, in large alluvial flats, are most numerous where the current is exceedingly slow; for slight obstacles change the course, throwing the current from one side to the other. Between the mouth of the Ohio and the Gulf of Mexico (Head of the Passes), the length of the Mississippi is 1,080 miles; and the actual distance in a straight line about 500 miles.

Pot-holes are incident to the process of erosion, when the waters flow in rapids over a bed of hard rocks. The rushing waters make the large loose masses to revolve or rock, and this wears the surface beneath, and gradually deepens it; and then the rapid whirl begins which carries around stones and pebbles, and keeps up the wear. The "Basin," in the Franconia Notch (White Mountains), is a pot-hole in granite, fifteen feet deep and twenty and twenty-five feet in its two diameters. There are many pot-holes at Bellows Falls, on the Connecticut; others on White River, in the Green Mountains, and elsewhere. One of those on the White River is fifteen feet deep and eighteen in diameter; another, twelve feet deep and twenty-six in diameter.

Nearly all the work of erosion, as well as of transportation, is carried forward in times of floods. Streams that are sluggish and impotent in the dry season, or even burrow out of sight, become torrents of tremendous power during rains. The rivers of some dry countries, like Australia, spread out in immense floods in the rainy season, and are strings of pools in the dry.

Occasionally storms pour down the rain in vast volumes, suddenly making torrents in the mountain valleys of thirty to sixty feet in depth, which tear away forests and remove whole hill sides to the lower plains.

The *bursting of lakes*, is one of the consequences of heavy rains, though often due to undermining by subterranean waters, or to tunneling of the banks by burrowing animals (p. 608). The floods so caused have the character of those arising from a sudden precipitation of rain in the mountains, but sometimes with vaster results, the water plowing profoundly into the slopes before it, and spreading the gravel

or earth, uprooted trees, and the contents of the lake basin, far and wide.

Again, in some countries the rains are excessive. At Paramaribo, in Dutch Guiana, the annual fall is 229 inches, or 19 feet; and south of Bombay, in the Western Ghauts at Mahabaleshwar, at a height of 4,200 feet, the annual amount is 302 inches, equivalent to a layer 25 feet deep, which the rivers carry off and work with.

3. *Erosion processes; the force concerned.* — Erosion from the mechanical action of water is carried forward (1) through the *impact* or blows of the water; (2) through the *abrasion* of the bed and sides of the channel by transported sand, gravel, etc.; and (3) through the *mutual abrasion* (or the corrasion) of transported particles or masses, by which these are made more transportable and their removal facilitated.

(1.) *By impact.* — The force of the impact of running water is expressed, in pounds, by the general equation $P = 0{\cdot}9702\, n\, s\, v^2$, in which v is the velocity in feet per second, s is the greatest transverse section of the body in square feet, n a coefficient varying with the form of the body; and 0·9702 is the quotient from dividing the weight of one cubic foot of water ($62\frac{1}{2}$ pounds) by $2g$ (p. 639). Supposing the greatest transverse area to be 1 foot: for a simple plate the value of n is 1·86; for a cube, 1·46; for a prism, placed end on, with square flat base and length three times the breadth, 1·34; and the least amount, for any prism with flat base, 1·25; for a sphere, 0·51; for some rounded forms, only 0·25. If the cylinder has a hemispherical end to face the current, the impact is half less than for one with a flat end; and if it ends in an equilateral cone, the impact is reduced to one fourth of that where the end is flat.

In accordance with the above, the force of impact against a flat plate a foot square, in a current of five miles an hour (or $7\frac{1}{3}$ feet per second), will be nearly 100 pounds; in one of twenty miles an hour, or four times five, 16 times that for five miles, and so on.

On the other hand, if the surface struck be a hemispherical *concavity*, the impact would be very much greater than for a flat surface, the value of n being about two for a hollow hemisphere with the concavity to the current. These results of experiment and mathematical calculation show that it is not possible to measure the force exerted in the movements of a river; and also that the concavities and deep recesses or channels among the rocks along the sides of a stream give the blows great power. (See for the force of wave impact, p. 671.) Moreover, all rocks are more or less divided up by joints; very many are laminated in structure; and most of them are in beds with some spaces between the beds; or they have interlaminations of weaker layers (layers easily eroded or decomposed) whose removal makes the needed

recesses; and thus the opportunities for tearing away masses by simple impact are great, especially when a stream has rocky walls, and the flood season has given the waters their maximum volume and velocity. The Colorado region affords just the conditions for such action, especially since the rocks are, for the most part, horizontal and not very hard. The blows also find much material already half decomposed, which they easily carry away. Great devastations are often made by this means when a flooded stream descends between earthy, forest-covered banks. By the same means, bends may be made in a stream, or cut away, or a new channel may be opened through alluvial flats, to the sea. But in this, and frequently other parts of its work, impact is aided by abrasion.

This erosion by impact is exemplified in the gold washings of the Sierra Nevada and other regions, where a stream, brought from a high level, is directed in a large jet against the compacted auriferous gravel. The hard gravel-bed melts away with wonderful rapidity before the blows.

(2.) *Abrasion.* — The transported sand and gravel which is carried by a current along the bottom or sides of a stream acts like the emery of an emery wheel, yet under only slight pressure. The particles, and especially the pebbles or stones, that are thrown by violent torrents against the surfaces within reach, whether those of other stones and pebbles or of solid rock, work more effectively, but less constantly. Together they tend to clear a rapid stream of the stones in its bed and enlarge as well as deepen its channel. At the same time the transported particles are wearing upon one another, tending to reduce the material to that fine impalpable state in which even slow-moving waters will transport them. This mutual abrasion is largely the cause of the rarity of pebbles along the lower part of some rivers.

Abrasion is also carried forward, in the case of a waterfall, by means of the spray sent off from the water at its final stroke; and, when there is an air chamber behind the fall, through the forcible movement of the air caused by the fall, an effect that was first observed by James Hall at Niagara.

4. *Effect of the Earth's rotation on River-erosion.* — The earth's eastward rotation, together with the increase in rate from the pole to the equator, tends to throw the waters of streams in the northern hemisphere against the *right* bank (the right, looking down stream), and, in the southern, against the *left*. Although the ratio between the impact on the two banks differs little from equality, the difference is sufficient to cause an undermining of earthy deposits and make the bank struck the high and steep one, and the other low. The expression for this ratio at the depth z, is $g z + b v w \sin l : g z$, in which b is the

breadth of the stream, v its velocity, l the latitude, and w the angular velocity of the earth about its axis (Cambridge Mathematical Tripos, 1875). With a stream 1,000 feet wide, the ratio for the impact on the two sides at a depth of 10 feet, would be as 461 to 460. The effects have been observed in many parts of the world where the deposits intersected are earthy, and the pitch of the surface is very small and has the direction of the stream. They are marked along the great rivers of Siberia and Russia, on others in Southern France, on the streams intersecting the low land of the Atlantic border of the United States (Kerr), and on those of Southern Long Island (E. Lewis).

5. *Topographical Effects of Erosion.* — The topographical effects of erosion depend on several conditions, — as (1) the durability of the rocks, (2) their structure, and (3) their stratification.

1. *Durability of the Rocks.* — Granite is well known to run up into lofty needles (or *aiguilles*), as in the Alps and, still better, the Organ Mountains of Brazil, and some peaks in the Castle Rock range, a few miles southwest of Mount Shasta, California. But there are varieties crumbling easily on exposure; and these occur only in broad, massive elevations. The hard argillyte (roofing-slate) often forms bold, craggy heights, while soft argillaceous shales make only tame hills and undulating plains.

The refractory quartzytes and grits, which make little or no soil, stand up in rude piles and massy brows of nearly bare rock.

2. *Structure.* — When there are no planes of structure, as in true granite, the rock may rise into lofty peaks, with rounded surfaces. Slow denudation goes on over all sides of the peak, either from trickling waters or from frosts, and may gradually narrow it into the model *aiguille.* But, when the rock has a cleavage-structure, like the schists and slates, its heights are rough and angular, and its *aiguilles*, if any are formed, are more apt to be pyramidal than conical. The lofty domes of the Yosemite region have been described as owing their forms to a cleavage or jointed structure in the granite, parallel with the surface.

The joints in slates or sandstones often lead to forms resembling walls and battlements, when exposed in cliffs (Fig. 88, p. 88). The architectural effect of the columnar cleavages of trap or basalt is shown in Fig. 115, p. 108.

3. *Stratification.* — The results with stratified rocks differ according to (1) the position of the strata, and (2) their nature.

If the strata are *horizontal*, or nearly so, and *hard*, and *similarly so* throughout, the elevations have generally table summits, with vertical rocky brows facing the lower lands. The river-valleys are profound, and often inaccessible for long distances, owing to the boldness of the precipices. The flooded waters of the valley wear the rocks at the base of the precipice, and so undermine it, and make avalanches of rock which keep the front nearly vertical. Some varieties of these valleys are shown in Figs. 1079, 1080. Other topographical effects are described, in the remarks on the erosion of valleys, p. 643. If the rock is firm, like most limestones, it may rise into lofty, few-angled sum-

Fig. 1081.

Fig. 1082

mits, especially when erosion has been preceded by fractures; as in the Alpine heights of the Wetterhorn and its associates, near Grindelwald, in the Bernese Oberland.

If *horizontal*, or nearly so, but of *unequal hardness*, the softer strata are easily worn away, undermining the harder strata; the table-lands have a top of the harder rock, and the declivities are usually banded with projecting shelves and intervening slopes.

Figs. 1081, 1082, represent the common character of such hills.[1] A number are shown in Fig. 1080; in the Colorado region, they have been called *Mesas*, from the Spanish for *table*. In some parts of the Rocky Mountain slopes, the thick gravel deposits are covered with streams of lava of great thickness; and table mountains are common in such regions (Fig. 1120, p. 741).

Elevations thus left prominent, after denudation around, have been called hills, or mountains, of *circumdenudation*. Figs. 1083, 1084, are other examples.

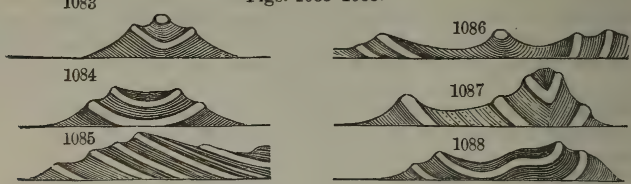
When the beds are *inclined* between 5° and 30°, and are alike in hardness, there is a tendency to make hills with a long back slope and bold front; but, with a much larger dip, the rocks, if hard, often outcrop in naked ledges.

When the dipping strata are of unequal hardness, and lie in folds, there is a wide diversity in the results on the features of elevations.

Figs. 1083, 1084, represent the effects from the erosion of a *synclinal* elevation consisting of alternations of hard and soft strata. The protection of the softer beds by the harder is well shown. This is still further exhibited in Figs. 1085–1088.

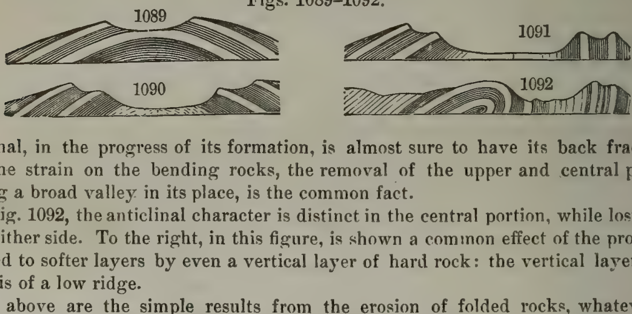
Anticlinal strata give rise to another series of forms, in part the reverse of the preceding, and equally varied. Figs. 1089–1092 represent some of the simpler cases.

Figs. 1083–1088.



When the back of an anticlinal mountain is divided (as in Figs. 1089–1092), the mountain loses the anticlinal feature; and the parts are simply *monoclinal* ridges. As the

Figs. 1089–1092.



anticlinal, in the progress of its formation, is almost sure to have its back fractured, from the strain on the bending rocks, the removal of the upper and central portion, making a broad valley in its place, is the common fact.

In Fig. 1092, the anticlinal character is distinct in the central portion, while lost in the parts either side. To the right, in this figure, is shown a common effect of the protection afforded to softer layers by even a vertical layer of hard rock: the vertical layer forms the axis of a low ridge.

The above are the simple results from the erosion of folded rocks, whatever the agency concerned. They serve as a key to the complexities of features common through a large part of the Appalachians and other regions of folded rocks, where synclinal and anticlinal axes are in numberless complicated combinations, rendered doubly puzzling by faults. See, further, pages 93–98, and beyond, page 786.

The outlining of mountain-ridges and valleys has been sometimes produced by subterranean forces, uplifting and fracturing the strata;

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[1] For Figs. 1081–1092, and the views they illustrate, the author is indebted to the volume on *Coal and its Topography*, by Lesley. In a long chapter on "Topography as a Science," this author has given the results of extensive personal observation.

but the final shaping of the heights has been due to erosion, and mostly, as has been stated, to erosion by fresh waters. This cause has been in action ever since continents began to be; and it has been thus making earth and gravel for stratified rocks, as well as gorging hills and mountains. The Appalachians have lost by denudation much more material than they now contain. Mention has been made of faults of ten thousand feet or more, along the course of the chain, from Canada to Alabama. In such a fault, one side was left standing ten thousand feet above the other, enough to make alone a lofty mountain; and yet now the whole is so levelled off that there is no evidence of the fault in the surface-features of the country. The whole Appalachian region consists of ridges of strata isolated by long distances from others with which they were once continuous. Fig. 103, p. 96, and Fig. 1134, p. 786, represent cases of this kind. The anthracite coal-fields of central Pennsylvania were once a part of the great bituminous coal-field of western Pennsylvania and Virginia (Fig. 613, p. 310). They now form isolated patches; and formations of great extent have been removed from over the intervening country. The Wahsatch, Uintah, and other related mountains of the Rocky Mountain region have been spoken of as remnants of great formations that once covered the country to a much higher level; and probably the portion left is not a hundredth part as great as that which has been carried off by the plundering waters. And all this erosion was accomplished after the commencement of the Tertiary era.

In New England, there is evidence of erosion on a scale of vast magnitude, since the crystallization of its rocks. On the summit-level between the head-waters of the Merrimac and Connecticut, there are several pot-holes in hard granite; one, as described by Professor Hubbard, is ten feet deep and eight feet in diameter, and another twelve feet deep. They indicate the flow of a torrent for a long time, where now it is impossible; and the period may not be earlier than the Quaternary. Many other similar cases are described by Hitchcock.

These examples of denudation are sufficient for illustration. The other continents furnish cases that are no less remarkable.

2. Transportation; Deposition.

1. Material transported and deposited.

The *materials transported* by running waters are (1) stones, pebbles, sand, and clay or earth; (2) logs and leaves from the forests, and sometimes trees that have been torn up or dislodged by the current; (3) mollusks or their shells, worms, insects, etc., attached to the logs or leaves; (4) occasionally larger animals, that have been surprised and drowned by freshets, or bones that have been exhumed by the waters.

The earthy material and stones have all come from the rocks. And among the agencies producing them, besides that of the wear and tear from rivers, there have been also the wear and tear from the ocean's waves and currents; the wear and tear from moving ice or glaciers, producing masses of all sizes, from that of a large house to the impalpable dust or clay that makes the outflowing waters milky for scores of miles away; the tearing action of freezing; tearing by the roots of growing trees (p. 607); the eroding and crumbling process of decomposition (p. 704), — a much more efficient agent than all the above, and largely preparatory for their action; the tearing from varying temperature; and in volcanic regions the rending effects of volcanic forces (p. 733). The rounded shapes of stones (often flattened, if the rock whence they were derived was schistose or laminated) have come from mutual abrasion while in the transporting water or ice; but also from surface decomposition, and the action of change of temperature. Stones rarely come in rounded forms directly from the rocks, and when so it is usually owing to decomposition along fractures (p. 87).

Besides these materials, waters carry also matters in *solution.*

2. Transporting Power of Water and its Effect on Decomposition.

The transporting power of water increases rapidly with the velocity, and partly in consequence of the fact that the weight of stones is a third to a half less in water than out of it, — the loss being equal to the weight of an equal volume of water. It is usually stated that in a current exceeding $\frac{1}{4}$ ft. per second (about $\frac{1}{6}$ m. per hour) fine mud or *silt* will be moved, that is, *scour* will take place over such a bottom; exceeding $\frac{1}{2}$ ft. ($\frac{1}{3}$ m. per h.), clay; 1 ft. ($\frac{2}{3}$ m. per h.), sand; 2 ft. ($1\frac{3}{8}$ m. per h.), gravel; 4 ft. ($2\frac{3}{4}$ m. per h.), loose stones. According to the experiments of M. Dubuat, a current of 4 miles per hour (or 6 ft. a second) will transport stones having a diameter of $2\frac{1}{3}$ in.; of 2 m. per h., 0.6 in.; of $\frac{2}{3}$ m. per h., 0.064 in., or fine sand; of $\frac{1}{3}$ m. per h., 0.016 in., or fine earth or clay.

For material of like density, *the mean diameter of the largest transported particles* varies as the square of the velocity; or, for any material, the *weight* varies as the 6*th power of the velocity.*

Experiments made in France in 1878 by M. Jacquet, engineer in chief, give greater scouring force to a given current: a current of 1.09 per h. (1.64 ft. per second) transporting particles 0.40 inch in diameter; of 2.18 m. per h., 1.60 inches; of 3.38 m. per h., 3.90 inches; of 4.36 m. per h., 6.70 inches. The rates are probably those that would just move the particles along the bottom.

In ordinary free transportation the stones or particles go over the bottom in a series of long arches, though the finer material *appears* to be carried without sinking. The very finest of clayey material sometimes remains suspended indefinitely, and because, according to the experiments of Prof. W. T. Brewer, it is in a colloidal state, analogous to that of gelatinous silica. This author found that such clouded waters became clear on freezing. The addition of a saline solution greatly hastens the deposition of sediment.

Mr. Babbage observes that, taking four kinds of detritus, of such a size, shape, and density that they would sink — the *first* kind 10 feet an hour, the *second* 8, the *third* 6, the *fourth* 4, then, if a stream containing this detritus were 100 feet deep at mouth, and entered a lake having a uniform depth of 1,000 feet, and a rate of motion of two miles an hour, the first kind would be carried 180 miles, before the first portion would reach bottom, and would be distributed along for 20 miles; the corresponding numbers for the others would be for (2) 225 and 25; (3) 360 and 40; (4) 450 and 50. Thus, four kinds of deposits would be formed from the same stream and be distributed for different distances along the bottom.

Thus, as a stream decreases in velocity, it *assorts according to size of particles deposited;* so that, (1) *the rate of flow determines* the *order of deposition* and *the arrangement of material;* and conversely, (2) *the coarseness or fineness of a bed* is evidence, in general, *as to the rate of flow of the depositing waters.*

An important exception to this relation between size of particles and hydraulic value, noticed and made the subject of special investigations by Professor Hilgard, arises from the tendency of the finer kinds of sediment, if the water is not absolutely quiet, to agglomerate their particles, if not over 1 mm. in diameter, into larger particles, or to *flocculate,* as he terms the process, and so take the hydraulic value of coarser sediments. He shows that fine river deposits consist largely of such *flocculated* particles, and that the fitness of soils for tillage depends largely on the porous condition thus derived.

Assorting according to hardness is another effect of erosion and transportation. The softer minerals are ground to the finest powder before the harder; and hence the former are most likely to constitute the finest deposits. Of rock materials, the two chief kinds are feldspar and quartz. The feldspar is most easily ground up; so that the two become widely parted by prolonged water movements, the quartz being left in coarser particles behind, while the feldspar is often carried on to make fine beds by itself. Quartzytes and felsytes are hence natural results of erosion, in regions of metamorphic rocks, when the feldspar has not become decomposed.

3. Amount of Material transported and deposited by Rivers.

The amount of transportation going on over a continent, especially in seasons of floods, is beyond calculation. Streams are everywhere at work, rivers with their large tributaries and their thousands of little ones spreading among all the hills and to the summit of every mountain. And thus the whole surface of a continent is on the move toward the oceans. The amount transported is a measure of the amount

lost by the land, as well as of that gained by the river plains, lakes, and seas.

The *amount of silt* carried to the Mexican Gulf by the Mississippi, according to the Delta Survey under Humphreys & Abbot, is about 1-1500th the weight of the water, or 1-2900th its bulk; equivalent for an average year to 812,500,000,000,000 pounds, or a mass one square mile in area and two hundred and forty-one feet deep.

The following table contains the ratio of sediment to water by weight, as obtained by the Delta Survey, and also the results of other investigations. It is from Humphreys & Abbot's Report (p. 148): —

	Ratio.	Time.
Mississippi R., at Carrollton, by Delta Survey,	1 : 1808	12 mos., 1851–1852.
Mississippi R., at Carrollton, by Delta Survey,	1 : 1449	12 mos., 1852–1853.
Mississippi R., at Columbus, by Delta Survey,	1 : 1321	9 mos., 1858.
Mississippi R., at Mouths, by Mr. Meade,	1 : 1256	2 mos., 1838.
Mississippi R., at Mouths, by Mr. Sidell,	1 : 1724	1838.
Mississippi R., at Various places, Prof. Riddell,	1 : 1245	14 days, summer of 1843.
Mississippi R., at New Orleans, Prof. Riddell,	1 : 1155	35 days, summer of 1846.
Rhone, at Lyons, by Mr. Surell,	1 : 17000	1844.
Rhone, at Arles, Messrs. Gorsse & Subours,	1 : 2000	4 mos., 1808–1809.
Rhone, in Delta, Mr. Surell,	1 : 2500	
Ganges,	1 : 858	

The bulk may be calculated, by taking 1.9 as the specific gravity of the material.

The annual discharge of sediment from the Ganges has been estimated at 6,369,000,000 cubic feet, or 756,200,000,000 pounds. The Nile brings down annually nearly 300,000,-000,000 pounds.

Besides the material held in suspension, as these authors observe, the Mississippi *pushes* along into the Gulf large quantities of earthy matter; and, from observations made by them, they estimate the annual amount thus contributed to the Gulf to be about 750,000,000 cubic feet, — which would cover a square mile 27 feet deep; and this, added to the 241 feet above, makes the total 268 feet.

This amount is equivalent to an average of $\frac{1}{4920}$ of a foot annually from the whole drainage area of the river; or, in other words, the area would be lowered by it, on an average, one foot in 4,920 years. The Ganges works faster, the amount it transports to the sea being such as would lower its drainage area, on an average, a foot in 1,880 years. All the rivers that enter the ocean or the seas over the land, are working in the same way, and with results to the continental surface mostly between these two extremes.

Mr. T. Mellard Reade makes out that the water which annually runs off from the area of England and Wales, about 68,451,000,000 tons, carries to the sea 8,370,630 tons of solids in solution, or 1,223 parts in every 10,000 of water, consisting of about 0.95 of calcium and magnesium carbonates and sulphates, 0.166 of sodium chlorid, and the rest nitrates, sodium carbonate, alkaline sulphates, silica and iron sesquioxyd; and at 15 cubic feet to the ton, the denudations thus occasioned would equal one foot in 12,978 years. Prestwich obtained in a similar calculation, one foot in 13,000 years for the calcium carbonate carried off by the Thames from the chalk, greensand, and oölitic formation. The total annual denudation for England, from this source alone, is thus esti-

mated to be 143·5 tons. The Rhine, according to Reade's calculations, removes about 92·3 tons in solution per square mile; the Rhone, 232 tons; the Danube, 72·7 tons; the Garonne, 142 tons; the Seine, 97 tons. From these data the conclusion is reached that over the world the average annual amount of rock-material dissolved and carried off by rivers is about 100 tons per square mile, of which about one half is probably calcium carbonate, one fifth calcium sulphate, 7 silica, 4 each of magnesium carbonate and sulphate and sodium chloride, and 6 of alkaline carbonates and sulphates. The annual amount of detritus brought down by the Danube is about $\frac{1}{3000}$th of the water, or three times the amount of solids in solution. Taking the amount of solids removed mechanically at six times that in solution, the whole amount for the globe of denuded material annually would be 600 tons per square mile.

While the land loses through erosion, the gain of the oceanic depressions, or of its borders, is exceedingly small. C. G. Forshey, after stating that the Gulf of Mexico has an area of 600,000 square miles, an average depth of 4,920 feet, and is about 85,000,000,000,000,000 (or 85 quadrillions) of cubic feet in contents; that its whole drainage area is 2,161,890 square miles, and the amount of fresh water it receives from this area is 37·78 trillions of cubic feet; adds that if empty, it would take its tributary rivers at this rate 2,250 years to fill it with water, or the Mississippi alone, 4,000 years. Consequently, if all the rivers contribute on an average 1-2600th their bulk of detritus, it would take nearly 6,000,000 years to grade the depression up to the sea-level, or for the Mississippi alone, about 11,000,000 years.

Mr. Forshey estimates, after two years of observation by him, the amount of silt *pushed* along by the Mississippi river *three times* that held in suspension, instead of one-ninth, the amount allowed by Humphreys and Abbot.

The quantity of wood brought down by some American rivers is very great. The well-known natural "raft," obstructing Red River, had a length, in 1854, of thirteen miles, and was increasing at the rate of one and a half to two miles a year, from the annual accessions. The lower end, which was then fifty-three miles above Shreveport, had been gradually moving up stream, from the decay of the logs, and formerly was at Natchitoches, if not still farther down the stream. Both this stream and others carry great numbers of logs to the delta.

4. Distribution of the Transported Material.

The transported material of rivers is distributed —

(1.) *Along the channel*, in sand-flats, and mud-flats, and over the bottom, and also in lakes.

(2.) Over the flood-grounds, supplying what these may annually lose during floods, and adding, in places, to their height, thus making *alluvial formations*, and, about lakes, *lacustrine* deposits or formations.

(3.) Along the shores of the ocean, or of interior seas, making deltas, and shore and off shore deposits, and contributing to the extension seaward of coast lines and the making of marine formations.

1. *Along the Channel.* — Sand-flats and sand-bars are made in broad channels, when the flow is not rapid enough throughout the breadth to sweep all the transported material down stream. The chief current or currents make their own deep passage-way; either side, the detritus drops because of the slower flow, and raises the bottom more

or less, or to the surface, according to the degree of slowness, the eddying currents, and the supply and fineness of detritus. The trend of the shores, pitch of the bottom, and other causes, locate the swifter currents in the channel, and thereby tend to locate the banks or reefs. A stranded log may change the course of the former, and thereby the positions of the latter; and so may high floods, and also the growth of bars. The lodging of drift-wood on a sand-bar may serve to increase the accumulation over it, and so change the bar into a wooded island. Moreover, high floods rob the bars at the same time that they add to them, or they may sweep them away, even if already an island, to form other bars and islands. They push along the movable detritus of the river's bottom, and also drop more to keep it generally at the old level. Thus all is movement and change along a river's channel. In a bend, the concave side receives the stroke of the waters and is the deep-water side, and the convex is usually a shallow point made partly of material from the opposite.

When two rivers unite they often make shoals for one another, one throwing a bar across the channel of the other through the descending detritus of flood waters. The waters of the Upper Mississippi are pushed to the opposite shore by the contributions of a tributary, and a deep, still-water, navigable area made above the junction, and rapids below. Further, the tributary, if not in flood at the same time, will have its mouth filled with sand-bars by the greater river, and often, also, in spite of its floods, if not too rapid in the flood. This subject is well illustrated in Reports on the Mississippi and its Tributaries by General G. K. Warren.

2. *Over the Flood-grounds.* — The flood-grounds are under water only in times of floods, and so the flow over them is less rapid than over sand-bars. They have, therefore, a still better chance to get the detritus of the flooded stream. Moreover, the laden waters rest long over their lower parts after the flood ceases. The flood-grounds lose from their surface by the floods, and may, in parts, be cut away to open new channels; but they generally gain as much as they lose, or more. Along the sides of the channel they are usually built up higher than elsewhere, owing to the material lodged there by the stream, in its frequent occasions of moderate floods when the waters scarcely rise over them, being often detained by bushes. Along the Lower Mississippi the pitch of the flood-plain from the river amounts, on an average, to seven feet for the first mile. (H. & A.)

The deposits of the flood-grounds may be the finest of silt, or the coarsest of gravel and stones, according to the region and the pitch of the stream. The course of a tributary from a mountain region over the flood plain is often marked by a wide bed of stones.

Alluvial Fans. When a flooded stream descends along a steep ravine, the detritus carried down is piled up at the foot of the slope over the plain, making a section of a very low cone, usually 3° or less to 8° or 10°, called by Drew, from their shape, *Alluvial fans.* The streams producing these "fans" are small ones, having more transporting than denuding power. The material is bedded, but concentrically, or parallel with the curved surface. When such "fans" are afterwards cut through by the little stream, and then partly worn away by the floods of the river in the valley which they border, and then formed anew at an outer and lower level, and so on, the bedding becomes quite complex in its directions and abrupt transitions; and there are parts of successive "fans" at different levels. (Q. Jour. Geol. Soc., xxix., 441, 1873.)

Fig. 1093. Delta of the Mississippi.

3. *Delta Formations.* — The larger part of the detritus of a river is carried to the ocean (or lake) into which it empties; and it goes to form, about the mouth of the stream, more or less extensive flats. Such flats, when large and intersected by a network of water-channels, are called *deltas;* they reach a large size only where the tides are quite small or are altogether wanting. The greatest river in China,

the Yang-tse, has no delta, but enters the ocean in one stream four miles wide. The tide rises there about seven feet.

According to Humphreys & Abbot, the outer crest of the bar of the Southwest Pass (the principal one) of the Mississippi advances into the Gulf 338 feet, over a width of 11,500 feet, annually; and the erosive power is only about one tenth of its depositing power. The depth of the Gulf, where the bar is now formed, being 100 feet, the profile and other dimensions of the river, in connection with the above-mentioned rate of deposit, give for the difference between the cubical contents of yearly deposit and erosion 255,000,000 cubic feet, or a mass one mile square and nine feet thick: this, therefore, is the volume of earthy matter pushed into the Gulf each year at the Southwest Pass. The quantities of earthy matter pushed along by the several passes being in proportion to their volumes of discharge, the whole amount thus carried yearly to the Gulf is 750,000,000 cubic feet, or a mass one mile square and twenty-seven feet thick. As the cubical contents of the whole mass of the bar of the Southwest Pass are equal to a solid one mile square and 490 feet thick, it would reqnire fifty-five years to form the bar as it now exists, or, in other words, to establish the equilibrium between the advancing rates of erosion and deposit. About one third of the area of the delta is a sea-marsh, only two thirds lying above the level of the Gulf. Professor E. W. Hilgard has shown that, about New Orleans, the modern alluvium has a depth of only thirty-one to fifty-six feet, there existing below this the alluvial clay, etc., of the Port Hudson group (p. 548).

Deltas are formed from the conjoined action of the river and the ocean, and are sometimes called *fluvio-marine* formations (p. 682). The delta of the Mississippi (see preceding page, Fig. 1093) commences below the mouth of Red River, where the Atchafalaya bayou begins, which is the first of the many side-channels that open through the great flats to the Gulf. The whole area occupied by it is about 12,300 square miles. Thus much has the river encroached on the outline of the Gulf; what amount in its depth, by its contributions of silt, is beyond calculation. The material which reaches the Gulf is mostly drifted westward toward Galveston. Other deltas, as those of the Nile, Ganges, and other great rivers, differ little, in the instruction they afford, from that of the Mississippi.

The contributions of rivers have added largely to the seashore plains of all of eastern North America, from Texas to Florida, and from Florida to New Jersey, as illustrated under the subject of the Ocean.

5. Structure of Formations.

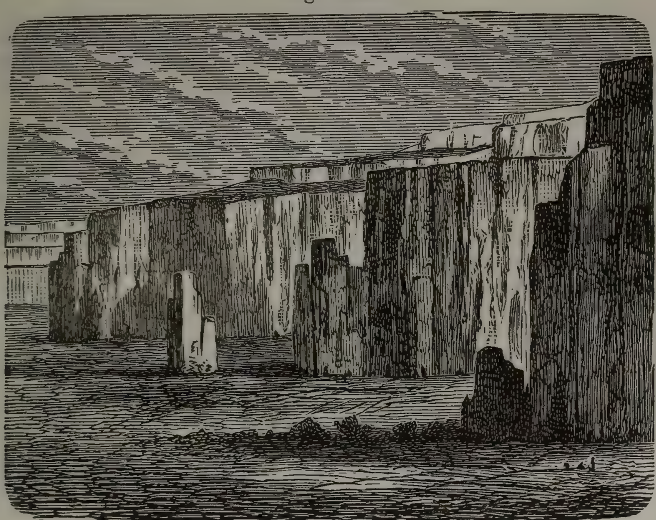
(*a*.) *Ordinary stratification.* — Stratification is for the most part a result of alternation in the conditions attending deposition. The variation from floods to low waters, and all changes in rate of flow, result usually in making a succession of unlike layers. When a current carrying sediment is long sustained at a given rate, the deposit may have throughout a uniform texture; but only slight changes in rate will cause changes in the depositions from coarser to finer, or the reverse. Even the alternations of night and day may be registered if the waters vary in amount through the melting of ice in the mountains.

Again, bedding may result without such changes. The material from successive floods may be of one kind, all of it a fine earth, and yet the deposit be stratified. In the alluvial deposits from a flood, the little layer is begun with a relatively rapid rate of deposition and finished with a slower, as the flood declines, and hence its upper and lower portions will differ as to coarseness and density; and so with those that follow.

A wave movement in a lake is sufficient to stratify the falling sediment, since each vibration of the water involves an alternation of action and comparative quiet.

If alternations of conditions are absent, a deposit of silt or earth

Fig. 1093 A.



Lœss formation on the Hoang-ho, in the Province of Shansi, China.

may be without division into layers. The *flocculation* of particles in fine sediments also tends to make deposits without distinct planes of bedding, as shown by Hilgard.

The fine earthy terrace-formation of the broader part of large river valleys is often of this character. The lœss deposits of the Lower Mississippi and the Rhine (referred to on pages 68, 549, 550, and 559) are examples. While such deposits have no thin layers, like those of ordinary clays, there are usually distant divisions into beds; and these often become very distinct through the shelves made in it by erosion. The loose material, sometimes several hundred feet thick, is easily cut through by the streamlets or streams the rains make, and the great plains are consequently reduced frequently to a region of pinnacled areas, amphitheatres, and narrow passages, confined by vertical walls,

much like the Tertiary "Bad Lands" of the Upper Missouri. The annexed cut (from Richthofen's China) represents a common scene on the Hoang-ho, whose lœss deposits are of great extent. The vertical structure of the beds, made apparent by the erosion, may be due in part to the easy percolation of waters through it; for these waters as they descend would become calcareous, from the calcareous particles of the formation; and then the deposition of the calcareous material (calcium carbonate), during the intermissions in the rains, would take place in vertical lines or planes. Calcareous concretions are common; and vertical tubular holes occur in much of the Chinese lœss, attributed to rootlets.

The fine texture of the lœss proves that it was made under comparatively quiet conditions; and the height of the great terrace-plains above the river-bed of the valley, indicates that they were formed during an era of enormous and long-continued floods as well as nearly lacustrine conditions, — such floods as could have come only from the melting of the ice of a Glacial era prolonged by a connection of the valley with extensive glacial mountains.

The valleys of the Rhine and Danube commence in the Alps; the Mississippi received waters, as the great glaciers melted, through its Rocky Mountain tributaries and the ice of the mountain glaciers for a long era after that of the Lake Superior and Winnipeg region had disappeared; and the Hoang-ho, of Northern China, whose modern floods are vast, drains for hundreds of miles the lofty Kuenlun Mountains. A Glacial era that covered the mountains of Europe with ice, would have added immensely to the ice of the loftier Asiatic Mountains, since the isotherms of the globe are under general laws; and it would have ended, over all the northern continents alike, in floods proportioned to the amount of ice, making violent streams, and coarse beds (if there were pebbles or stones within reach), in some parts, and earthy depositions wherever the waters, owing to the lay of the land at the time, made lakes, or expanded into regions of quiet flow, along the valleys.

The lœss of China, and even that of the Mississippi, Rhine, and other valleys, is attributed by Richthofen chiefly to wind-drift deposition. But, as regards the Mississippi, the continent on one of its sides, and for a long distance on the other, was under forests or prairies, and hence afforded only locally, if at all, material for wind-transportation. Moreover, the winds, besides shifting endlessly, make drift heaps and not level plains, except it be in desert regions. Even a small bush will make eddies that will pile up the sand. Further the lœss plains of the Mississippi are one with the plains of coarser material and distinct bedding to the north, and part of the great system of terrace or Champlain deposits of the continent.

The height of flood-plains in a valley is determined approximately by the height of the floods. Floods raised to different levels, would tend to make plains at different levels, or terraces, in the valleys of a country. If a high flood level had thus made a high flood plain or terrace, other terraces might be formed at different levels below this during the decline of the flood, if it were slow and intermittent in progress. The enormous floods from the melting ice of a Glacial era, since it would be subject to just such slowly progressing and intermittent decline, because of the thickness of the ice, and its long continuance about the mountains, might, therefore, leave the valleys with one or several ranges of terraces.

Stratification is only sparingly produced by a settling of sediment in any one spot in the order of coarseness or density of particles; for there are usually currents that produce a down-stream assorting. The finest of earthy material is often held long suspended, and it may be slowly deposited over flood-made beds, and top them with a thin layer.

(*c.*) *Sandbars; obliquely laminated Structure.* — The sandbars of a river channel, as shown by General Warren, have usually a slight pitch up stream and a *steep one* at the down stream extremity. The sand is carried on until the crest is reached, when it falls over and stops in the still water below. The stratification will correspond with the surface; and as the sand-bar extends itself down stream by the additions to its extremity, the pitch of the down-stream extremity will determine *oblique* bedding parallel with it.

The pushing of detritus along the bottom of a river must result in similar oblique bedding. But in both cases, oblique deposition will be followed by deposition in horizontal beds when the floods are declining, so that combinations of the two, often of a very irregular character, should exist in such deposits. A *ripple mark* has the same form as the sandbar and for essentially the same reason.

B. SUBTERRANEAN WATERS.

1. The Source and Condition of Subterranean Waters.

A large part of the water which reaches the earth's surface descends into the soil, and becomes subterranean.

It mostly passes downward until it reaches a compact layer of some kind, — as of clay, or agglutinated pebbles ("hard-pan"), or of hard rock, — and upon this it may accumulate largely during rainy seasons. And if the layer has a regular pitch in any direction, these waters will flow along the sloping surface, and often gather from different directions around into streams. They may descend between the *inclined* beds of a region, and continue on the descent for hundreds and even thousands of feet in depth.

A coral island but ten feet high and a few hundred yards wide, and consisting of coral rock up to the water-level with coral sands above, generally yields, from excavations to the surface of the rock beneath, a sufficient supply of water for its inhabitants, and all of it has come from the rains. The fresh water, moreover, is sufficient to exclude, by its seaward pressure, all ingress of salt water. If this is true on a coral island, the subterranean waters derived from the rains over large hilly islands or lands should be very great. The proportion which becomes subterranean depends on the permeability or cavernous nature of the subjacent rocks or material. Crystalline rocks absorb al-

most none; cavernous limestones sometimes take in whole rivers; some sandy regions are always dry except when it rains.

On the long southern side of Long Island the surface rises from the shore line at a mean grade of 20 feet a mile for about six miles, and beneath the sloping surface, a water level or plain (as proved by digging for wells which descend to it) commencing at low-tide level, rises at an even grade of 12½ feet a mile. The material at and below the surface is porous sand, more or less pebbly; and out of the 42½ inches of rain (snow included) which annually falls, nearly 40 per cent. become absorbed and subterranean. The Brooklyn Engineer, Mr. T. Weston, observes that these subterranean waters supply the small streams of the surface with the chief part of their water, and discharge a large amount into the sea; and after a careful survey of a part of this southern slope, west of Brooklyn, 73·64 square miles in area, he reported that the water supply from the surface streams was, on an average, 22 per cent. of the precipitation, or 30,000,000 gallons a day; that 15 per cent. additional came out along the shores of the bays; and that at least 40,000,000 gallons per day might be obtained in reservoirs by proper arrangements. Mr. Weston holds that the water plain is the upper limit of a water region which extends from this plain vertically downward to and below the sea-level, and that the height and pitch of the water-plain is determined by friction from the sand, and not by the existence of a "hard-pan" layer underneath.

The water which has descended between inclined layers both nearly or quite impervious, is like that in a long inclined tube, under hydrostatic pressure proportional to the vertical height of the source; and when a boring is made through the overlying beds to such a subterranean stream the water rises and is sometimes thrown out in lofty jets. In the annexed cut (Fig. 1094), *a b* represents a water-supporting layer, *b c* the boring; and *c d* the jet of water. The rise of the jet falls far short of the height of the source, because of the friction and the resistance of the air. Such wells are called Artesian wells, as they were first made in the district of Artois, in France. They are now an important means of securing water for irrigation and other purposes in various parts of the world. Even the dry plains of the Rocky Mountain slopes and California have secured large supplies of water by such means. They are seldom successful when the boring is made into crystalline rocks; but are often so when penetrating only the stratified gravels of a region, there being usually in such formations some hard-pan layer or clayey beds, which hold the water.

Fig. 1094.

Section illustrating the origin of Artesian wells.

The Artesian well of Grenelle, near the Hotel des Invalides, in Paris, is 2,000 feet deep. At 1,798 feet, water was struck; and it darted out to a height above the surface of 112 feet, and at the rate of nearly one million of gallons a day. The pressure indicated by the jet was equal to that of a column of water 2,612 feet high, or 1,160 pounds to the square inch. Another, in the north of Paris, has been carried down to a depth exceeding 2,000 feet, with a diameter of more than four feet to the bottom. All but 157 feet of it is below the sea-level.

Another well, in Westphalia in Germany, is 2,385 feet deep.

An Artesian boring at St. Louis has been carried to a depth of 3,843½ feet, but without obtaining a flow of water to the surface; the last 250 feet were in granite of the Archæan, so that the whole of the Paleozoic of the region, from the Carboniferous downward, was passed through. (Broadhead.) A well at Louisville, Kentucky, 2,086 feet deep, supplies an abundance of water, though a little brackish.

In some cases, subterranean waters are under pressure from an accumulation of gas which is in a state of compression sufficient to send them to the surface without other aid, whenever reached by a boring.

The subterranean waters sometimes, and perhaps often, form large underground rivers. Those of the caverns of Kentucky and Indiana have their cascades, like ordinary rivers, and may be navigated for long distances. It is stated that there are a hundred thousand miles of underground chambers in the Subcarboniferous limestone of Kentucky (Shaler), and several thousands in that of Indiana; and others, also, though of less extent, in Silurian limestones. Into these caverns rivers enter and become "lost rivers," while from others issue great streams, whose former history is unknown. The Cave of Adelsberg, 22 miles northeast of Trieste, has its river; and the Jura Mountains send forth streams to daylight full grown. On all shores the outward flow of the under-ground waters prevents the in-flow of the salt water. Springs are common on shores; and, occasionally, their waters rise in large volumes in a harbor, or out to sea, some miles distant from a coast.

2. Mechanical Effects.

Subterranean waters act mechanically by erosion, and by softening or loosening permeable beds, and adding to their weight.

1. *Erosion.* — Subterranean streams produce erosion, like running water above ground, and may excavate a channel in the same way. Caverns are made partly by erosion and partly by the dissolving action of water; and the great extent of the caverns of Kentucky and other parts of the Mississippi Valley may be viewed as examples of what has been accomplished by underground streams. A common effect of such excavations is the production of subsidences of the soil and overlying rocks, and the formation of *sink-holes.* Small shakings of the earth may be a consequence of the fractures of undermined strata.

2. *Softening Beds and adding to their Weight.* — The following are among the effects consequent on this softening of beds by water.

(1.) *Land-slides.* — Land-slides are of three kinds: —

(*a.*) The mass of earth on a side-hill, having over its surface, it may be, a growth of forest trees, and, below, beds of gravel and stones, may become so weighted with the waters of a heavy rain, and so loosened below, by the same means, as to slide down the slope by gravity.

A slide of this kind occurred, during a dark, stormy night, in August, 1826, in the White Mountains, back of the Willey House. It carried rocks, earth, and trees from the heights to the valley, and left a deluge of stones over the country. The frightened Willey family fled from the house, to their destruction; the house remains, as on an island in the rocky stream.

(*b.*) A clayey layer, overlaid by other horizontal strata, sometimes becomes so softened by water from springs or rains, that the superincumbent mass, by its weight alone, presses it out laterally, provided its escape is possible, and, sinking down, takes its place.

Near Tivoli, on the Hudson River, a subsidence of this kind took place in April, 1862. The land sunk down perpendicularly, leaving a straight wall around the sunken area, sixty or eighty feet in height. An equal area of clay was forced out laterally underneath the shore of the river, forming a point about an eighth of a mile in circuit, projecting into the cove. Part of the surface remained as level as before, with the trees all standing. Three days afterward, the slide extended, partially breaking up the surface of the region which had previously subsided, and making it appear as if an earthquake had passed. The whole area measured three or four acres.

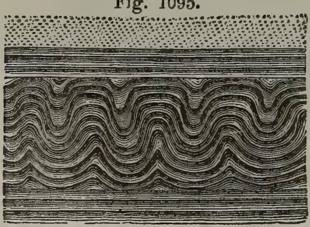
(*c.*) When the rocks are tilted, and form the slope of a mountain, the softening of a clayey or other layer underneath, in the manner just explained, may lead to a slide of the superincumbent beds down the declivity.

In 1806, a destructive slide of this kind took place on the Rossberg, near Goldau, in Switzerland, which covered a region several square miles in area with masses of conglomerate, and overwhelmed a number of villages. The thick outer stratum of the mountain moved bodily downward, and finally broke up and covered the country with ruins, while other portions were buried in the half-liquid clay which had underlaid it and was the cause of the catastrophe.

Similar subsidences of soil have taken place near Nice, on the Mediterranean. On one occasion, the village of Roccabruna, with its castle, sunk, or rather slid down, without destroying or even disturbing the buildings upon the surface.

Besides (1) the transfer of rocks and earth, land-slides also cause (2) a scratching or planing of slopes, by the moving strata and stones; (3) the burial of animal and vegetable life; (4) the folding or crumpling of the clayey layer subjected to the pressure, where the effect does not go so far as to produce its extrusion and destruction; while the beds between which it lies are only slightly compacted or, are unaltered. Fig. 1095 is a reduced view of a layer thus plicated, from the Quaternary of Booneville, N. Y. Vanuxem illustrates the facts there observed by him, with this and other figures (N. Y. Geological Report), and attributes the plications to lateral pressure, while the layer was in a softer state than those contiguous.

Fig. 1095.



Plicated clayey layer.

(2.) *Mud-lumps, Mud-volcanoes.* — The shallow waters within one to three miles of the main channel or mouth of the Mississippi River (see map, p. 659) are dotted with what are called mud-lumps, — convex or low-conical elevations, sometimes 100 feet or more in diameter, — showing their tops at the surface. They originate in upheavals of the soft bottom. Once formed they discharge mud from the top, which gives to the material of the low cone the structure of a volcanic cone, the successive layers being, however, of mud, and but a fraction of an inch thick. They finally collapse; and then the cavity of the cone sometimes becomes the site of a pool of salt-water, like the lake in an extinct volcano. They are formed, according to Prof. E. W. Hilgard (from whose description in the "American Journal of Science," III., i., the facts here given are cited, and who adopts, in the main point, the view of Lyell), through the pressure of the surface deposits on a layer of mud which overlies the Port Hudson clay, or Champlain alluvium (p. 547). Some carbo-hydrogen gas is given out, arising from the decomposition of animal or vegetable matters in the mud.

3. Moisture confined in Rocks.

The amount of moisture in different rocks varies with their kinds and compactness of texture.

In 1853, Durocher published some results of experiments with regard to the amount of water contained in different crystallized minerals, giving, among them, ·0028 to ·0269 per cent. for orthoclase, or common feldspar; ·0127 for porphyry; ·0203 for euryte, a feldspathic granite, etc. Delesse made further examination of rocks, in 1861, and found the amount of moisture in coarse granite 0·37 per cent., in euryte, 0·07; in milky quartz, from a vein, 0·08; in flint, from the chalk at Meudon, 0·12; in a compact Tertiary limestone (Calcaire grossière), 3·11; in chalk, from Meudon, nearly 20 per cent.; in a quartzose sandstone (grès de Fontainebleau, near Meudon), 2·73. Hunt, in some experiments, the results of which were published in 1865, obtained for the amount of moisture absorbed, after drying at a temperature between 150° F. and 200° F.: for Potsdam sandstone, three specimens, 2·26 to 2·71 per cent.; other three, 6·94–9·35; for Trenton limestone, 0·32 to 1·70, the former for a black variety; for the Chazy rock, an argillaceous limestone, 6·45 to 13·55; a crystallized dolomite, of the Calciferous formation, four specimens, 1·89 to 2·53; two other specimens, 5·90 to 7·22; for the Medina argillaceous sandstone, two specimens, 8·37 to 10·06.[1]

The facts, as first suggested by Sæmann, early in 1861, and afterward at more length by Delesse, show that the thickening of the supercrust, by the addition of sedimentary beds, has been attended by the withdrawal of water from the oceanic and other superficial basins. The metamorphism of strata has expelled this moisture, to a large extent, from the beds thus altered, yet not wholly. The average amount, in granite, syenyte, porphyry, and all Archæan rocks, is not over 0·06 per cent.; while in other rock formations it may be 2·5

[1] Durocher, Bull. Soc. Geol., x., 431, 1853; Delesse, ibid., xviii., 64, 1861; Hunt, Amer. Jour. Sci., II., xxxix., 193.

per cent.; and in superficial clays and gravels it is at least 10 per cent.

If the thickness of the supercrust over the continental portion of the globe averages five miles, and the average volume of moisture in the formations, both metamorphic and unaltered, be 2·5 per cent., the whole amount of water absorbed and confined would be a fortieth of five miles, or about 650 feet in depth, for the area of the continents. The deposits over the oceanic basins have relatively little thickness. Whatever reasonable allowance be made for them, the whole loss to the ocean waters, in depth, from this source, will not exceed 400 feet. This confined water, while a feeble agent of change at the ordinary temperature, is one of immense importance when much heat is present.

As Delesse states, the water confined in terrestrial plants and animals is another part taken permanently from the oceans, since the commencement of Paleozoic time.

2. THE OCEAN.

1. Oceanic Forces.

The ocean exerts mechanical force, by means of its —

1. General system of currents; 2. Wind-waves and currents; 3. Tidal waves and currents; 4. Earthquake-waves.

The force of moving salt water is the same as for fresh water, except the difference arising from the greater density of the former, — its specific gravity being *one thirty-fifth* to *one-fortieth* more than that of fresh water, and a cubic foot weighing 64 lbs.

The *specific gravity* of sea-water varies for different parts of the ocean. For the waters of the Southern ocean, it is 1·02919; the Northern, 1·02757; equatorial 1·02777; Mediterranean Sea, 1·0270–1·0294; Black Sea, 1·01418 (Marcet). In most seas receiving large rivers, and in bays, the density is least. The specific gravity of the water of East River, off New York City, at high tide, is 1·0208 (Beck).

1. General System of Currents.

The system of oceanic currents is briefly explained on pages 38–42. It is part of the organic structure of the globe, irrespective of its age or condition; for, whatever the temperature of the poles, there must always have been *warmer* tropics, under the path of the sun.

The prominent characteristics of these currents, bearing on their mechanical effects in geological history, are the following: —

1. *The rate of movement is slow.* — The maximum velocity of the Gulf Stream is five miles an hour, and the average less than one mile and a half.

The Gulf Stream is most rapid off Florida, where the hourly rate is three to five miles; off Sandy Hook, it is one mile and a half. The rate of flow of the polar current

is less than one mile an hour. Kane, while shut up in the Arctic, was carried south by the current, some days, about half a mile an hour. The great oceanic current of the eastern South Pacific varies from three miles an hour to a fraction of a mile; and across the middle of the ocean it is barely appreciable. The current in the Indian Ocean, where most rapid, has the hourly rate of two miles and a quarter.

In past geological ages, the rapidity of these great oceanic currents must have been less than now, if there was any difference, because of the less difference of temperature between the equator and the poles, and hence feebler trade-winds.

2. *The currents are generally remote from coasts, and are seldom appreciable where the depth is less than one hundred feet, and very feeble where less than one hundred fathoms.* — Owing to the depth of the oceanic movement, the waters are diverted along the borders of the oceans by the deep-sea slopes of the continents. The Gulf Stream approaches the coast at Cape Florida, and somewhat nearly at Cape Hatteras and Cape Cod; but, off New Jersey, its western limit is eighty to one hundred miles distant, along the limits of the deep-sea slope. It does not reach into the interior of the Mexican Gulf.

The polar or Labrador current, which is mostly a sub-current, comes to the surface along the same slope, west of the limit of the Gulf Stream, and is slightly apparent on the shore-plateau, but rather by its temperature than by the movement of the waters. The more western position of the limit of the polar current is explained on page 39. The fact that it has not more rapid movement on the great shore-plateau is evidence that it belongs to the deep water. This appears, further, in the current's underlying the Gulf Stream, and its banding the stream with colder and warmer waters, as shown by the Coast Survey, under Professor Bache. The observations of the survey have proved that there are mountain-ridges apparently parallel with the Appalachians, along the course of the stream, in its more southern part, off the Carolinas, and that, above these ridges, the surface-waters are cooler, owing to the lifting upward of the polar current by the submarine elevations.

Where the current flows close along a coast or submarine bank, or by an oceanic island, it may produce some eroding effects.

3. *As the position of the main flow of the currents is determined partly by the trend of the continents, their courses may have been different in former time from what they are now, provided the continents, or large portions of them, were sufficiently submerged.* — Small subsidences would not suffice to produce a diversion from their present courses, for the reason just given. Even the barrier of Darien might be removed, by a submergence to a depth of five hundred feet, and probably one thousand, without giving passage to much, if any, of the Gulf Stream. If, however, the isthmus were so deeply sunk that the Gulf Stream

passed freely into the Pacific (the West India islands being also in the depths of the ocean, as would be necessary for the result), a great change would thereby be produced in the temperature of both the Atlantic and the Pacific, — a loss of heat to the former and a gain to the latter. (See Physiographic Chart) But no facts yet observed prove this supposition to have been a realized fact since the opening of the Silurian age. A shallow-water connection across the isthmus between the two oceans probably existed as late as the Cretaceous, as has been inferred from the parallel series of representative species now existing on the two sides.

Besides the general system of currents, which has been considered, there are currents between the ocean and some confined seas opening into it, which are due to the evaporation going on over the surface of those seas. The consequent diminution of water causes a flow at surface from the ocean, to supply the loss. This happens at the Straits of Gibraltar, opening into the Mediterranean. At bottom, there is a flow outward, of the denser water. In many seas of this kind, the accessions from rivers more than supply the amount removed by evaporation; and these produce an out-current at the entrance. The Black Sea, by losing much of its salt, is rendered less dense than the Ægean, to the south, and hence there is an under-current into it at the Dardanelles.

2. Ordinary Wind-Waves and Currents.

1. *Waves.* — The winds are an almost incessant wave-making power. Even in the calmest weather, there is some breaking of wavelets against the rocky headlands or exposed beaches; and, with ordinary breezes, the beaches and rocks are ever under the beating waves, night and day, from year to year. Most seas, moreover, have their storms; and in some, as those about Cape Horn, gales prevail at all seasons. The breakers on the shores of the Pacific are especially heavy, on account of its extent and depth. Through a large part of the ocean, the winds are nearly constant in direction either for the year or half-year.

The highest waves measured by Scoresby rose 43 feet above the trough between them, or 21½ feet above the main water plane or plane of rest. In a wave each particle of water moves in a circle about its centre of rest, — a circle of 21½ feet radius in a wave of 43 feet. But these circles at a depth of only *one* wave-length have a radius 1-535th of that at the surface, and at a depth of *two* wave-lengths, 1-300,000th; so that if, for the 43-foot waves, the wave-length — or the distance between the crest of two consecutive waves — is 300 feet, the circle at a depth of *one* wave-length will have a diameter of 4-10ths of an inch, and at two wave-lengths, 1-1200th of an inch. Consequently the movement of the heaviest waves is exceedingly slight at a depth of 100 fathoms.

Waves made by winds as they advance toward a shore over a shelv-

ing bottom, change from oscillatory to translation waves, that is, to those in which there is actual forward movement in the water. They "break" when the depth of the water is a little more than the height of the crest above the undisturbed level or plane of rest. At the instant of breaking, the upper part is thrown forward, while the lower part flows backward as the "under-tow."

If there is deep water quite up to vertical shore cliffs, the waves rise and fall but do not break, and the action has small mechanical force. But on shelving shores, up which the waves advance and plunge, the force is often very great.

Stevenson, in his experiments at Skerryvore (west of Scotland), found the average force of the waves for the five summer months to be 611 pounds per square foot, and for the six winter months 2,086 pounds. He mentions that the Bell Rock Lighthouse, 112 feet high, is sometimes buried in spray from ground-swells, when there is no wind, and that on November 20, 1827, the spray was thrown to a height of 117 feet, — equivalent to a pressure of nearly three tons per square foot. During a westerly gale in March, 1845, his dynamometer registered a pressure of 6,083 lbs. per square foot, which gives for the velocity per second, by the formula, $\sqrt{\frac{Pg}{64}}$ (P being the pressure in pounds and 64 the weight of a cubic foot of sea-water), $\sqrt{\frac{6083 \times 32{\cdot}2}{64}} = 53{\cdot}32$ feet. The hydrostatic pressure due to a wave 20 feet high is only about half a ton to the square foot, and the rest of the force comes from its velocity. Mr. Stevenson states that on one of the Hebrides a mass of rock of about 42 tons weight was gradually moved in a storm five feet; with each incoming wave it was made to lean landward, and the back run uplifted it with a jerk, leaving it with little water about it. Hagen reports that in the harbor of Cette a block of concrete, measuring 2,500 cubic feet and weighing probably 125 tons, was moved on its bed over three feet.

2. *Currents.* — Winds also cause *currents.* The prevailing winds of an ocean, like the trades (p. 43), cause a parallel movement in the surface-waters; and, when the direction is reversed for half the year, as in the western half of the tropical Pacific, the current is changed accordingly. These currents become marked along shores, and especially through open channels. The great currents of the ocean are attributed by some physicists to the force of the prevailing winds. Prolonged storms often produce their own currents, even in mid-ocean, and more strikingly still among the bays and inlets of a coast.

The forcing of waters into bays, whether by regular winds or by storms, causes a strong under-current outward, like that from the

tides. This happens when the entrance of the bay is broad, so as to allow of an in-flow over a wide area, while the deep-water channel is narrow; and especially so, if the entrance to the bay is narrowed by a bar or reef. In some cases, ships lying at anchor feel this under-current so strongly as to "tail out" the harbor, in the face of a gale which is blowing in.

3. The Tidal Wave and Tidal Currents.

The tidal wave differs from ordinary waves in many respects; (1) in having an extra-terrestrial origin — the attraction of the moon and sun — owing to which, the ocean feels the impulse to its bottom, and the wave is a translation-wave; (2) in the movement being westward as a consequence of the earth's eastward revolution, and hence in having the same rate of movement as the earth, or 1,000 miles an hour at the equator (that is, movement in wave-motion, not in water); consequently (3) in having for the length of a single wave 12,000 miles, the ebb and flow occupying together twelve hours. The Pacific is too narrow from east to west to contain at once much over half of the wave-curve, and the North Atlantic could hold transversely but a quarter of it. After leaving the Pacific, its course is northwesterly in the Indian Ocean, and the same also in the Atlantic. The height in the middle Atlantic is very small, but as the depth diminishes on soundings, the wave increases in elevation, and its translation character becomes more and more appreciable. Still, at the prominent headlands of the continent its height is only 1 to 2 feet; being but 2 feet at Cape Hatteras after traversing 80 miles of soundings, the outer and deepest part of which is 100 fathoms.

The height of the tide is augmented by converging coast-lines. The eastern coast of North America has, as laid down by Bache, a great "Southern Bay," between Florida and Cape Hatteras, a "Middle Bay" between Hatteras and Nantucket, and an "Eastern Bay," north of Nantucket; and, while at Southern Florida the tide is 1 to 1½ feet, at Cape Hatteras 2 feet, at Southeastern Nantucket only 1 foot, the height within the "Southern Bay," at Savannah, is 7 feet, in the "Middle," at the entrance of New York Bay, 5 feet, and in the "Eastern," at Boston, 10 feet; and in the narrow Bay of Fundy, 40 feet, and sometimes 70 feet at the spring tides.

Other examples of unusual tide are the following: At the entrance to the British Channel, England, the spring tides are 18 feet, and within it, at the mouth of the Severn, 45 to 50 feet; at the Bay of St. Michel (west coast of Normandy), France, 45 to 48 feet; at the extremity of the Persian Gulf, 36 feet; while in the Gulf of Mexico, at the mouth of the Mississippi, it is only 2 feet; and in the Mediterranean, because of its little size, no tide is appreciable.

Where the tide enters a large bay or channel by two passages, the height varies according as the waves from the two directions are both at high water when they come together, or not. At Batscham, in Tonquin, two tidal waves (from the China and Indian seas respectively) meet when it is *high* water with one and *low* with the other, and the result is no perceptible tide.

The tidal waters, owing to the translation character of the wave on soundings, often become tidal currents along shores. On the open shores the translation action is small, though perpetual; but at the entrance to bays, as at New York Bay, it is a strong tidal current. Along southern Long Island (see map, p. 422), there is some westward action from the movement toward New York Bay. In Long Island Sound, the translation wave, entering by the east passage, travels along the Sound westward, sweeping each coast as far as the rocky intricate passage called Hell Gate (near where the Sound approaches New York Island), and here it meets the wave coming from the west through New York Bay. The two usually encounter one another with the water at different heights, and the violent currents and whirlpools of the place are the consequences. Mr. J. E. Hilgard, of the Coast Survey, states that if there were a partition across at Hell Gate the waters would stand on one side sometimes five feet higher, and, at others, five feet lower, than on the other; and the difference, while less than this from more or less perfect overlappings of the two tidal waves, is often as much as a foot within the space of 100 feet These are illustrations of some of the kinds of action going forward along all continental borders. The tidal current may have the violence of a river-torrent, when the entrance to bays is of a kind to temporarily detain the waters, until the tide has so accumulated them that they rush forward with increased velocity, owing to the depth from the accumulation, so that the hinder part of the wave overtakes the front part, and all move in together. In the Bay of Fundy, the waters of the incoming tide are raised so high above their natural elevation, that, as they advance, they seem to be pouring down a slope, making a turbid waterfall of majestic extent and power, without foam.

Where the tide moves in all at once the phenomenon is called an *eagre* or *bore*. The most perfect examples are afforded at the mouths of the rivers Amazon, Hoogly (one of the mouths of the Ganges), and Tsientang, in China. In the case of the last-mentioned river, the wave plunges on like an advancing cataract, four or five miles in breadth and thirty feet high, and thus passes up the stream, to a distance of eighty miles, at a rate of twenty-five miles an hour. The change from ebb to flood-tide is almost instantaneous. Among the Chusan Islands, just south of the bay, the tidal currents run through the funnel-shaped

frith with a velocity of sixteen miles an hour. (Macgowan.) In the eagre of the Amazon, the whole tide passes up the stream in five or six waves, following one another in rapid succession, and each twelve to fifteen feet high.

The ebbing tide causes the *out-flowing* current, which is directly the counterpart of the in-flowing current. It is more quiet than the latter in its movement; but it is often a rapid and powerful current, because more contracted in width than that of the flow, — and especially so in bays in which the waters of a river add to the volume of the ebb.

The piling of the tide-waters to an unusual height in converging bays, raising them far above their level outside, is another cause of out-flowing currents. The flow is along the bottom, and it often has great power.

In consequence of the tidal movement carrying the waters up coasts, *the sea has its flood-grounds*, like rivers; but the floods occur twice a day, with each recurring tide. The tidal movement of the ocean is communicated to the water of rivers and the translation wave travels up stream, the salt waters following. It extends along Hudson River, to Troy, 150 miles, 50 miles up the Connecticut, 400 miles up the Amazon; and, rising above the level of the wells along the coast and the outlets of the subterranean streams, it acts, siphon-like, to raise their waters, so that such wells also have their tides. In the outflow the rivers regain their normal action and follow the salt waters out to sea, and extend, in the case of large rivers, far out, as a surface layer, over the heavier salt water.

4. Earthquake Waves.

In an earthquake, the movement of the earth may be either (1) a simple vibration of a part of the earth's crust; or (2) a vibration with actual elevation or subsidence. If submarine waves are produced, they have a forward impulse, and, in the second case, an actual forward movement or amplitude equivalent to the amount of change of level; in each case, therefore, they are *translation-waves.* They have great power; and, as there is no narrow limit to the amount of elevation which may attend an earthquake, such a wave may be of enormous height. The velocity of propagation varies as the square root of the depth, the number of miles per hour being 12·2 miles in a depth of 10 feet; 38·7 in that of 100 feet; 122·3 in that of 1,000. The wave is made of water taken from either side, and hence along the land the bottom is left bare for some distance out before each rise and plunge. An earthquake at Concepcion, Chili, set in motion a wave that traversed the ocean to the Society and Navigator Islands, 3,000 and 4,000

miles distant, and to the Hawaiian Islands, 6,000 miles; and on Hawaii it swept up the coast, temporarily deluging the village of Hilo. An earthquake at Arica, and other parts of southern Peru, August 14, 1868, sent a wave across the Pacific, westward, to New Zealand and Australia, northwestward to the Hawaiian Islands, northward to the coast of Oregon; and this was repeated in May, 1877.

2. Effects of Oceanic Forces.

The effects of oceanic forces are here treated under the heads of— (1) Erosion; (2) Transportation; (3) Distribution of Material, or Marine and Fluvio-marine formations.

1. Erosion.

Erosion by Currents. — Little erosion is done by the *great oceanic currents*, on account of their slow rate of motion, and their distance from the land. Still, the Labrador current, with its westward tendency (p. 40), acting against the submerged border of the continent, may have produced some results of this kind in past time, if not doing so now. It has been supposed that the course of the steep outer slope of this submerged border (p. 11) has been determined by the oceanic currents; but it is more probable that the position of the slope has directed the courses of the currents.

The *tidal flow* and *wind-currents* may produce results similar to those of fresh-water streams of equal velocity.

The *ebbing tide* and the *under-currents* act on the bottoms of inlets and harbors, and especially their channels, and are an important means of keeping them open to the ocean, and of modelling their forms.

2. *Erosion by Waves.* — The waves bring to bear the violence of a cataract upon whatever is within their reach, — a cataract that girts all the continents and oceanic islands. In stormy seas, they have the force of a Niagara, but with far greater effects; for Niagara falls into a watery abyss, while, in the case of the waves, the rocks are made bare anew for each successive plunge.

Much of their work is due simply to the impact of the water, the power of which is shown to be at times enormous by the facts cited on page 671. The rocks encountered are usually more or less jointed, and often laminated or bedded, and frequently there are alternations of softer and easily removed layers; so that the waters find or make recesses, to give greater effect to the plunge. The slight rocking of the immense slabs or blocks of jointed granite by the repeated blows, enlarges the openings and brings them sooner or later where gravity will finish the work of degradation. The Thimble Islands, of gneiss

and granite, on the Connecticut coast, illustrate well this action, and by the kind of rock as well as the results, show how destruction went forward when, as in Archæan time, the ocean had to work without the help of rivers. Cliffs are often made of horizontal beds, and then the rocks, when the beach is not wide enough to serve as a breakwater, are quickly undermined.

But simple impact is aided by abrasion, carried forward by the stones and gravel which the hurrying wave takes up and throws at the cliff. The dash forward and the flow backward, carry on the mutual abrasion of the sands, gravel, stones, and rocks of the shores, reducing the coarser to sand, besides grinding the sands to a finer powder. In view of the force at work it is not surprising that, in regions like Cape Horn, or the coast of Scotland, where storms are common, the cliffs should undergo constant degradation, and be fronted by lofty castellated and needle-shaped rocks, or that the land should yield before the encroaching sea. The long leathery seaweed of coasts, in some seas scores of yards in length, are a great protection to the rocks.

The cliffs of Norfolk and Suffolk, England afford an example that has been long under observation, as the country is one of houses and cultivated fields. Lyell states that in 1805, when an inn at Sherringham was built, it was fifty yards from the sea, and it was computed that it would require seventy years for the sea to reach the spot — the mean loss of land having been calculated, from former experience, to be somewhat less than one yard annually. But it was not considered that the slope of the ground was *from* the sea. Between the years 1824 and 1829, seventeen yards were swept away, bringing the waters to the foot of the garden; and in 1829 there was depth enough for a frigate (twenty feet), at a spot where a cliff of fifty feet stood forty-eight years before. Farther to the south, the ancient villages of Shipden, Wimpwell, and Eccles have disappeared. This encroachment of the sea has been going on from time immemorial. Many examples might be cited from the American coast; but none so remarkable have yet been described.

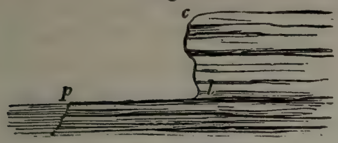
3. *The wearing action of waves on a coast is mainly confined to a height between high and low tides.* — Since a wave is a body of water rising above the general surface, and when thus elevated makes its plunge on the shore, it follows that the upper line of wearing action may be considerably above *high-tide* level.

Again, the lower limit of erosion is above *low-tide* level; for the waves have their least force at low tide, and their greatest during the progressing flood; and, when the waves are in full force, the rocks below are already protected by the waters, up to a level above low-tide mark. There is, therefore, a level of greatest wear, which is a little above half tide, and another of no wear, which is just above low tide.

This feature of wave action, and the reality of a line of no wear, above the level of low tide, are well illustrated by facts on the coasts of Australia and New Zealand. In Figure 1096 (representing in pro-

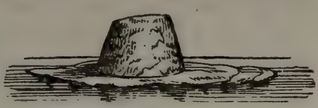
file a cliff on the coast of New South Wales, near Port Jackson), the horizontal strata of the foot of the cliff extend out in a platform, a hundred yards beyond the cliff. The tide rises on the platform; and

Fig. 1096.



Cliff, New South Wales.

Fig. 1097.



"The Old Hat," New Zealand.

the waves, unable to reach its rocks to tear them up, drive on to batter the lower part of the cliff. At the Bay of Islands, New Zealand, the rocks have no horizontal stratification; and still there is the same seashore platform; and an island in the bay (Fig. 1097) is called "The Old Hat." The *seashore platform of coral islands* has the same origin. The *stability of sand-flats* in the face of the sea is owing to this cause. In seas of high tides and frequent storms, the platform is narrow or wanting, owing to the tearing action of the heavier waves.

2. Transportation and Deposition.

1. *Characteristics of Sea-water.* — Owing to the greater density of sea-water, stones immersed in it lose 1–40th more of their weight than when in fresh water, and thus in the transportation of the same load the former would have less weight to carry. But, on the other hand, sediment falls in salt water *in a fifteenth of the time* it does in fresh, as first shown by Mr. W. M. Sidell, salt water having less cohesion than fresh; so that the transporting power is actually less.

Mr. Sidell, while studying the rate of deposition of the Mississippi at its mouth, experimented with solutions of common salt, epsom salt, and alum, as well as sea-water, and found that in river water the sediment took 10 to 14 days to settle, while the same, in saline solutions, settled in 14 to 18 hours. (Appendix A, Humphreys' & Abbot's Mississippi Report.) E. W. Hilgard observes that clay immediately settles if any considerable amount of lime or other neutral salt is present in solution; yet, should the water be alkaline, it will remain suspended indefinitely. He also states that the "settling" effect of alum appears to be mainly due to the precipitation of alumina by the calcium and magnesium carbonates which are present.

This is an important means of preventing the detritus of rivers from being carried into and wasted in the deep waters. Mr. Sidell thus explains the fact that the bars are formed *where the salt water is first met.* Moreover, since the tidal wave is a translation wave, and appreciably so in soundings, its action and that of wind-waves is to beat back the detritus contributed to the ocean by rivers and hasten its deposition. From these facts it is plain that no continent can contribute to the detrital accumulations of another continent, except through the aid of

icebergs. Had there formerly existed a continent in the midst of the present North Atlantic, America would have received from it no rock-material.

2. *The great Oceanic Currents.* — The great oceanic currents are too feeble to transport any material coarser than the finest detritus, and generally too remote from coasts to receive detritus of any kind. The Gulf Stream passes the channel between Florida and Cuba at a rate of five miles an hour; but Florida feels it very feebly, and, according to the dredgings under the direction of L. F. Pourtales, contributes nothing. On the Cuba side the water is deep, and the current comes close to the land; but the same authority states that the debris of the reefs, while found at considerable depths, even 800 fathoms, is not carried northward more than three or four miles.

The observations of Sir Wyville Thomson and others go to show that the bottom of the deep ocean is free from river detritus, and from such detrital sedimentary deposits as make up, exclusive of limestones, the strata of the land (see pages 611 and 686). But sea-weeds are borne along by such currents, and the animal life which they harbor. The Gulf Stream carries immense quantities of a floating Fucus, which is thrown off on the inner side of the current, into the interior region of the Atlantic, called, from the common name of the sea-weed, the *Sargasso Sea.* With the sea-weeds, there are various species of crabs, shrimps, bryozoans, fishes, and other kinds of marine life. Icebergs are carried along by such currents (p. 701), and deposits of large bowlders, as well as gravel and sand from the Arctic, have thus been made along the Labrador coast and over the Banks of Newfoundland. The cold, arctic currents which move slowly over the ocean's bottom have favored the migrations of marine Arctic and Antarctic life, and the passage of such species as can inhabit great depths even from one polar region to the other; and hence has come, it is supposed, a resemblance in the genera of the two distant regions.

3. *Ordinary Waves.* — The transporting power of waves is illustrated on p. 671. The great blocks torn off from submerged beds of rock, or loosened from the bottom, as well as the stones and sand, are thrown up the beach, and make an accumulation varying with the height of the tide and the force of the waves; and the winds add to the elevation by drifts as explained on page 632. The large rocks sometimes are overgrown with long sea-weeds which make them more easily transportable. Marine animals, or their relics, and sea-weeds, are also among the material thus accumulated; and occasionally large animals, as stranded whales, are added, not an infrequent event about the Chusan Islands in the China seas.

The sands and stones left below the highest reach of the breakers

are stratified mainly by the "undertow," and the beds have therefore a dip corresponding with that of the beach, which is usually about 7° to 8° with a low tide, but often 15° to 20° when the tides are high and the bottom outside drops off rather rapidly.

The deposits making the surface of a beach are more or less coarse, varying from stones to fine sand, according to the force of the waves; and the coarser kinds fail to be present only in regions where stones are not to be had along the shores. The plunging breakers and the powerful undertow sweep away the finer material.

Accumulations of iron sand or garnet sand are often made toward high-water mark, these materials being left behind because of their higher specific gravity. The finer material, which is constantly made by abrasion chiefly of the feldspar and other softer grains of the beach sands, but also of its silicious grains, is carried out by the undertow into deeper water, to add to the accumulations of mud in progress over the sea bottom. When corals and shells abound in seas these become the material that is ground up by the waves into beach sands. See p. 619.

Such seashore action thus tends to assort out the siliceous portion of the material exposed to the breakers, and make siliceous accumulations, and it has always been a common source of siliceous gravel deposits. But it is sure also to make mud deposits in the deeper waters; so that the two belong together, and are results of the same agency. *Coarse sand-beds, or gravel beds, can never have been made by beach action without the making also of mud-beds in regions not very far distant.* Moreover, *not a year has passed since granite and gneiss first existed in which quartzose sand-beds were not somewhere in progress.*

4. *Earthquake Waves.* — Earthquake waves commence their work at an unusual depth, through the retreat of the waters (p. 674), and tear up earth, rocks, and strata, with marine shells and relics, from regions that are at other times under the protection of the waters; and then the waters advance to an unwonted height, and make deposits of what they have gathered at varying distances inland, according to their gravity, besides devastating the country they cover. At the Lisbon earthquake of 1755, the oceanic wave had a height along the Tagus of 40 feet, at Cadiz, of 60 feet, on the shores of Madeira, of 18 feet, and 8 to 10 on the coast of Cornwall. The earthquake of 1746, on the coast of Peru carried a frigate several miles inland, besides deluging the seaport Callao, and the city of Lima seven miles inland. But the geological effects of such waves are small compared with those of ordinary waves; for the latter are in incessant action on all shores.

The tidal wave, as it swells over the land and covers the great tidal flats, often carries in little besides the weeds and sticks floating on its

surface. But in other places the movement is rapid, and, besides, a river or a cliff contributes sand and silt for transportation. This action is treated of in connection with the next subject, — that of tidal and wind-made currents.

5. *Tidal and Wind-made Currents.* — Tidal currents work in the same direction through the year, with only the variations that attend each tide. Wind-made currents vary in direction and force with the winds. But those of some directions are more prevalent than others in all seas; often the direction is constant for half a year or more; and in the line of the trades, it is uniform for the larger part of the year.

The materials transported and deposited are derived (1) from the degradation of coasts; and (2) from the detritus brought down by rivers. The latter is now the principal source; but the former was so in early times when the lands, and therefore streams, were small.

The tidal waves and currents often drift the detritus that is within reach along the coast, in the direction of the movement and thus make (1) lines of banks or sand flats parallel with the shores; (2) fill up bays or obstruct their entrances and widen the seashore flats; (3) cover the outside region of soundings with deposits. The wind-waves often aid much in this work; but when *from an opposing direction*, the combined action tends to plough into and sweep away the beach.

The coasts of Long Island afford a good example of the action where rivers have taken almost no part. On the map on page 422, the south side is seen to have for more than forty miles a nearly straight and narrow sand reef as the outer limit of as long a bay. There are entrances through it; but they are very small breaks in the line of reef. This reef has been made partly by the waves rolling in from the Atlantic, but more from the sands drifted along the coast by tidal and current action. The high bluffs of stratified gravel and sand beds, which make the shores toward Montauk Point, give way before the heavy surges; and besides making a very coarse, stony seashore, contribute sands for the reefs to the west. The inner shore of the long shallow bays is full of indentations; and these are evidence as to the character of the coast line as it was left at the last elevation of the land; while the straight-edged reef shows the effects of straight-line drifting from the debris of the projecting bluffs westward along the shores. The entrances through the reef are outlets for the tides by whose outflow they are kept open. After a time the waves throw into them so much sand as to obstruct them; and then at an unusually high tide or great storm, they open at a new point, or wherever there is least obstruction. Again, on the north side of Long Island, where also the tide moves westward, there are similar high cliffs of sand and

gravel for wave degradation; and, accordingly, long sand reefs stretch westward from the eastern capes of all the deep harbors, across the opening, sometimes nearly closing it against shipping, while depth enough exists inside for the largest of vessels. There being no rivers, the coast is at the mercy of the drifting tidal and current action.

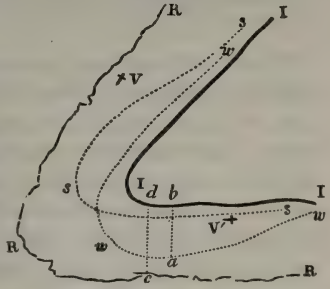
Similar facts are stated by Captain Davis, in his excellent paper on the geological effects of tidal action. He mentions the cases of long points thus made on the eastern extremity of Nantucket, where the current on the outside of the island sets from the west to the east, and from the south to the north. Vessels wrecked on the south side of the island have been carried by it, by piecemeal, eastward and then northward, to the beach north of Sankaty Head. The coal of a Philadelphia vessel, lost at the west end of the island, was carried around by the same route to the northern extremity.

The formation and lengthening of Sandy Hook — the sand reef five miles long forming the southern cape of New York Bay — is wholly due, as shown by Bache, to the action of tidal currents. A northerly current flows alike along the outer and inner sides, during both the ebb and flood tides, and the conflict of the two directs the deposition of the sands, and has made it in recent times elongate at the rate of a mile in sixteen years.

Where the wind-current changes semiannually, the accumulations made by the current when flowing in one direction are sometimes transferred to another side of an island or point, during the next half-year.

J. D. Hague states, that at Baker Island (of coral), in the Pacific (0° 15′ N., 176° 22′ W.), this fact is well exhibited. In Fig. 1098, I I I is the southwest point of the island, and R R R, the outline of the coral-reef platform, mostly a little above low-tide level; its width, *c d*, 100 yards. In the summer season, when the wind is from the southeast, the beach has the outline *s, s, s*; during the winter months, when the wind is northeast, the material is transferred around the point, and has the position *w, w, w*, having a width at *a b* of 200 feet. A vessel wrecked in summer, and stranded at V, was transferred to V′ in the course of the month of November.

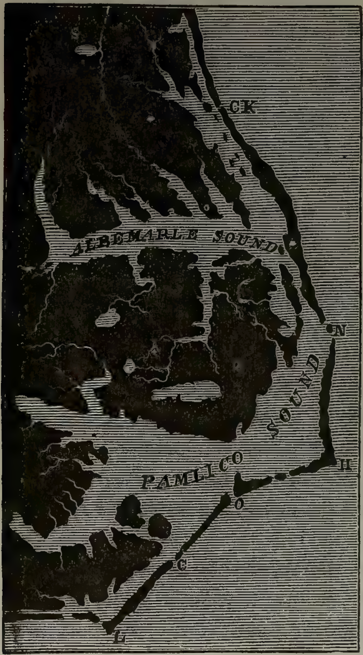
Fig. 1098.



The flow of rivers and the movements of the ocean are, in general, in direct opposition. The in-flowing tide sets back the rivers, quiets the waters, and floods the adjoining tidal flats; and, consequently, a deposition of detritus takes place over the flats, and especially about the mouth of the stream. The turn of the tide sets the river again in full movement; and it takes up the detritus deposited over its bed (but

only little of what fell over the flats), and bears it to the ocean. Here, the current loses much of its velocity, in the face of the waves, and with the spreading of the waters; and hence a deposition of detritus goes on in the shallow sea, off the mouth of the stream; and this continues until the tide stops anew the flow of the fresh-water stream. Between the tidal currents, especially the in-flowing, and the river, there is a region of comparative equilibrium in the two movements; and there the accumulations of sand or detritus take place, forming sand-bars.

Fig. 1099.



Fluvio-marine formation along the coast of North Carolina: CK, Currituck Inlet (to Currituck Sound); N, New Inlet; H, Cape Hatteras; O, Ocracock Inlet; C, Cove Inlet; L, Cape Lookout.

Humphreys and Abbot observe, in speaking of the Mississippi delta, that, as the river-water rises above the salt water, from its low density, there is a dead angle between the two. The current out of the Passes pushes sand and earth before it, until, reaching, it begins to descend upon the salt water of the Gulf; and here this material "is left upon the bottom, in the dead angle of salt water. A deposit is thus formed, whose surface is along or near the line upon which the fresh water rises on the salt water, as it enters the Gulf; and this action produces the bar."

Whenever there is a tidal movement along a coast the depositions from the discharging rivers will be most largely made against or toward the cape facing the incoming tide; that is, the western cape or side, in case the tidal movement is westward. If in such a case, the eastern or opposite side has a long projecting cape or breakwater, there will be the best possible conditions in the outline of the coast for retaining an unobstructed entrance. The long outstretching cape keeps the tidal current far out, so that the detritus cannot be driven into the mouth of the stream, but only to the western cape and to the shores and reefs farther west; a comparatively small stream may keep clear the channel of a bay so favored. But with the longer cape on the other side, the mouth of the river would be wide open to the incoming tide, and into it all the detritus would be thrown to choke it; consequently great reefs clog the entrance. Only a very large river could succeed in keeping open a deep channel under such conditions. The Connecticut River fails badly.

The distance of sand-bars or barriers off the mouth of a river generally depends on the size and strength of the river on one side, and the height and force of the tides on the other. Small streams are often blocked up entirely, by a sand-bar across their mouths; and the waters reach the ocean only by percolation through the beach. Large streams make distant sand-reefs or barriers, and keep open channels even in the face of the ocean. The attempt to block up the channels of a large harbor or bay by obstructions, like that in the case of the harbor of Charleston, where ships were sunk to fill the channels, is always a failure, because the force that made the channel still remains. Only by diverting the rivers that do the chief part of the work could such an attempt be effectual.

The North American coast, from New York to Florida, is fronted by ranges of barrier reefs, shutting in extended sounds or narrow lagoons. The preceding map of Pamlico Sound and the region about Cape Hatteras (Fig. 1099) illustrates this feature of the continent. The numerous rivers of this well-watered coast carry great quantities of detritus to the ocean, part of which is borne out to sea, to raise the great submarine plateau of the coast; and another part is added to the barrier and to the banks and flats of the Sound, and is drifted by the tidal current along the coast, in the same manner as along the south side of Long Island. The contraction of the Sound, which is going on by the additions to the flats and over its bottom, gradually prolongs the channel of the river toward the ocean. This gives greater force to the river-current; and it acts in conjunction with the strong ebb-tide, against the inner side of the barrier, in slowly wearing it away. At the same time, the outflowing stream and tidal current carry a greater quantity of detritus into the ocean, contributing sand to the beach, and through the drifting tidal movements, the finer detritus to the plateau, the nature of wave-action on a beach being such as to leave only the sand or coarser material. Thus, by a slow process, the mainland gains in breadth, and the river in length; and the barrier moves gradually seaward and keeps its even outline. In other cases, the lagoons inside of the barrier become filled; and a continuous marsh, and ultimately dry land, is made, out to the barrier. All the low lands along the eastern coast of the continent, and those bordering on the Gulf of Mexico, in most parts many scores of miles in breadth, have been made by such means and methods.

When the tides are very small, or fail altogether, the rivers may reach the sea by many mouths, without the formation of barriers, or, in other words, may form true deltas. The height of the tide of the Mexican Gulf, along the north shore, is but twelve to fifteen inches; and, consequently, while most streams, before even so small a tide,

have their bars and barriers, the great Mississippi sends its many arms far out into the Gulf, prolonging its channels in the face of winds, waves, and tides (Fig. 1093, p. 659). Incipient sand-bars at times form; but these serve only to divide one of the great channels, and make a new branch.

3. Structure of Deposits.

The kinds of deposits are as follows: —

1. *Beach Deposits:* Consist generally of sand or gravel, sometimes of large stones, the sands most mobile when wholly siliceous and when not very fine; often contain worn shells and other sea-relics; stratification irregular above high-tide level, but, below this, parallel to the sloping surface of the beach; often have *rill-marks* where half buried shells or stones have interrupted the flow of the waters down the beach.

2. *Sand-flats, Sand-bars, Sand-reefs:* Consist of sand, but sometimes of coarser material, and often blend with the beach; also graduate into *mud-flats* where sheltered from the open sea; upper surface commonly between high and low-tide level, but often below the latter, also sometimes raised by the waves and winds to a higher level; stratification horizontal or parallel to the upper surface; often covered by *ripple-marks*, when exposed at low tide, from the sweep of the tide over the surface, the waters pushing the sand into a ridgelet, as high as the force can make, and then plunging over the little elevation to begin another, thus making the first slope gradual and the closing steep; often have vertical borings made by sea-worms, mollusks, or certain kinds of Crustaceans (as species of the *Callianassa* family). Dead and worn as well as living shells, are common over its surface, and if emerged at low tide, the tracks of worms, mollusks, and, if a mud-bank, of birds.

3. *Bottom Deposits on Soundings outside of strong tidal currents:* Consist commonly of mud or silt, but often also of sand, and sometimes of gravel; stratification horizontal or nearly so; contain beds of living shells, and other marine species, differing in kind with the depth. The plateau off the Atlantic coast, 50 to 80 miles wide, Long Island Sound, and the bays of the coast, have deposits of this kind. Occasionally they contain objects of fresh-water origin contributed by the rivers, as floating plants, logs, transported shells, etc.

4. *Bottom Deposits beneath strong tidal currents:* Consist of mud, sand, or coarser material; stratification horizontal, but owing to the strong flow during the incoming tide and its alternation with high-water and low-water quiet and the ebbing tide, layers that are *obliquely laminated* alternate with ordinary layers. This oblique lamination

appears to be due to the same pushing and transporting action which forms the ripple-mark; the commencing push makes the gradual up-slope, — it may be several inches in vertical height, — and then the continued push carries on sands which fall down the steeper front slope, and keep falling, in successive impulses, and so produce a long series of parallel laminæ which dip at an angle ordinarily of 20° to 30°. Such deposits may have also the *flow-and-plunge* structure (p. 82), when the depth is small and the flow is accompanied with plunging waves. With a slower current, ordinary ripple-marks may be made. Wave-action has slight effect on the bottom, and even at a depth of 50 fathoms (p. 659), does not make ripple-marks.

The stratification in these different deposits is produced on the same general principle with that of alluvial beds, — *alternation in the conditions of deposition* (page 660). It seems surprising that the beds of sand made by the dashing waves over a beach should have structure of any kind; and yet in most cases the successive layers of deposition are very distinct after solidification has taken place, if not before. It is still more wonderful that the depositions by the plunging wave and the flow of a torrent together should consist of thin layers and show them perfectly in unconsolidated sand and gravel deposits. But in all wave-made depositions and in those formed under subordinate vibrations of the water, there is a difference of character in the upper and under parts of each deposited layer, however thin, because of the nature of wave or vibratory movements, as already explained.

The term stratification is used above for: —

(1.) A bedded structure due to alternations in the time or nature of the supply of material; in which the layers may be thick, as in ordinary sandstones and limestones, or thin as in most alluvial deposits.

(2.) A thin-bedded structure which comes from wave-action or vibratory or pushing movements attending depositions, as in the oblique lamination of the ebb-and-flow structure, and the flow-and-plunge structure, and also much of the thin bedding of clayey or earthy deposits, where horizontal instead of oblique.

(3.) A thin-bedded structure from either of the above sources that (1) gives a fissile character to the deposit, like that of shale; or (2) that leaves it still solid, as in some compact limestones, which structure is at times undistinguishable by the naked eye unless over weathered surfaces.

Moreover, the term is applied to a formation made of layers, — its ordinary and right use; or to a single layer of a stratified rock when it is made up of fine subordinate layers. The limestone just referred to and the cases under No. 2, are stratified in the two senses, that is, (1) in consisting of beds, and (2) in having each bed made up of subordinate layers. For the latter of these two kinds the distinctive term *straticulate* is appropriate. Agate, and much stalagmite, are straticulate, but not properly stratified.

The deposits in the bed of the deep ocean must be without even a straticulate structure, because the waters are unstirred by appreciable currents or vibrations.

As heretofore stated, the material of the bottom of the ocean, outside of a depth of one hundred feet, consists largely of Rhizopod shells (Foraminifers). Off southern New

England, at depths between 300 and 550 feet, from a region southeast of Montauk Point to that southeast of Cape Henlopen, the soundings, according to Bailey (Smithsonian Contrib., ii., and Am. J. Sci., II. xvii. 176, xxii. 282), consist *chiefly* of these shells. At greater depths, beyond the limit of the plateau, Pourtales found almost a pure floor of Rhizopods (Trans. Amer. Assoc. for 1850, 84, and Rep. Coast Survey for 1853 and 1858); and the facts have been confirmed by later investigation. The species are deep-water forms, differing thus from those of the New Jersey Cretaceous beds. Pourtales observes, in a letter to Professor Bache (dated May 17, 1862), that, along the plateau between the mouth of the Mississippi and Key West, for two hundred and fifty miles from the mouth, the bottom consists of clay, with some sand and but few Rhizopods; but, beyond this, the soundings brought up either Rhizopod shells alone, or these mixed with coral sand, Nullipores, and other calcareous organisms. The Rhizopod shells continue to a depth of 12,000 to 15,000 feet along with other life, as stated on page 611. But beyond this these shells are absent; and since they have reached the bottom elsewhere by dropping from various levels, and largely from near the surface, their absence at these depths is owing to the conditions of the region, and, probably, as Sir Wyville Thomson has suggested, to the solution of them by the carbonic acid present in the waters. The bottom is made for the most part of a red ooze colored by iron sesquioxide, which is supposed by him to be the earthy matter of the same shells, and probably more or less of volcanic ashes (p. 633). Over the bottom in the Pacific black nodules of manganese oxide occur which has been referred, but with a query, to the pyroxene of such ashes. The dissolving away of the coral rock of Bermuda has left a red soil which Thomson considers to have come from the corals, like the red ooze from the Rhizopods, though in each case these ingredients are only very sparingly present.

4. Action of the Oceanic Waters over a submerged Continent, and during a progressing Submergence or Emergence.

During a slowly progressing submergence of a continent the waves and marine currents would work over the loose earth, gravel, and alluvium of the surface for a depth of possibly a hundred feet or so, thereby changing them into marine deposits; the living species of the land and fresh waters would be destroyed and marine life would be introduced; and the general *features of the surface would be changed through a wearing off of heights and a filling of preëxisting valleys, and not by the excavation of valleys.* It might be supposed, at first thought, that the ocean would wash through the valleys with great excavating force, and make deep gorges over the surface. But from the present action on sea-coasts it is learned that with each foot of submergence, the sea-beach would be set a little farther inland, so that the whole would successively pass through the conditions of a seashore; and on existing seashores, the action in progress, instead of tending to excavate valleys, is everywhere wearing away exposed headlands, and filling up bays. The salt waters, in fact, enter but a short distance the river-valleys of a coast, because they are excluded by the out-flowing stream. The bottom of the Hudson is below the sea-level, for a long distance beyond the limit to which the pure ocean-water extends: the same is true of the St. Lawrence, and of many other rivers along the coast. During a progressing submergence, therefore, the ocean would have no power of excavating narrow valleys, unless they happened to be

open at both ends and of great breadth and depth, so as to allow the oceanic currents to sweep through.

As the submergence progressed, there would be, through wave-action, extensive degradation of the ridges and mountains over the surface, and a distribution of the detritus through the intervening depressions. In a subsequent emergence of the land, the mountains and ridges would be still further degraded, and the valleys filled by their debris. The laws of sea-coast action would again come into play, and the wear of all new headlands, and the filling of bays, continue to be the result, so long as the emergence was in progress.

If the continent were to a large extent without mountains as was the fact in early geological time, the broad flat surface might then lie slightly above or below the tide-level at once, or nearly simultaneously, so that, under a small change of level, the waves could sweep across the whole area and the deposits might have a continental extent. Through continental oscillations, causing slight emergences of large areas to alternate with varying submergences, variations in the formations would be produced, differences of depths and differences of currents causing transitions from arenaceous to argillaceous or to pebbly accumulations, or to clear waters fitted for corals and the other life which has contributed to limestone making.

3. FREEZING AND FROZEN WATER.

Water performs part of its geological work in the act of freezing, and another part when frozen, in the condition of snow and ice.

1. Water Freezing.

Rending and Disintegration from Expansion. — Water has its greatest density at 39°·2 F. (4° C.) On cooling below this it gradually expands; and on becoming ice, at 32° F., it has increased in volume 1-11th, or lineally, 1-35th, and diminished in density to 0·92.

Hence if freezing takes place in crevices, it opens and deepens them, and thus carries on a process of destruction. It tears to pieces rifted, jointed, and laminated rocks, separating often large masses; and as almost all rocks absorb moisture at surface, if not also throughout the mass, there are few that do not suffer some disintegration when exposed to icy weather. In cold latitudes rocky bluffs have usually, from this source, a long talus of broken stone, while, in the tropics, they are generally free from fragments. This kind of degradation has produced much of the soil and drift material of the globe.

As a body of water 35 feet wide will make 36 feet in width of ice, the freezing of the surface of small ponds may bring pressure against

the sides or their rocks, or cause fractures and ridges over the surface. But freezing usually begins about the shores, and in the expansion there, the ice slips over the water, leaving a central portion only to be thrown into a strain.

2. Ice of Rivers and Lakes.

Ice, forming along streams in which there are stones, envelops the stones in shallow water, even to a depth of two or three feet, or more in the colder climates. Other stones and earth fall on the ice from the banks. When the floods of spring raise the stream, and break up the ice, both ice and stones often float down stream with the current, or are drifted up the banks high above their former level, or are spread over the river-flats.

Ice sometimes forms about stones in the bottom of rivers, when the rest of the water is not frozen, and is then called *anchor-ice.* In this condition, it may serve as a float to raise the stones, and to transport them, with the aid of the current.

The same modes of transportation are exemplified in lakes as in rivers, except that there is less current; and the stones are mostly set back up the shore. Large accumulations of stray stones far above the ordinary level of the lake are in some places thus made.

3. Glaciers.

I. General Features; Formation, and Movement of Glaciers.

1. *Nature of Glaciers.* — Ordinary glaciers are accumulations of ice, descending along valleys from snow-covered elevations. They are ice-streams, 200 to 5,000 feet deep or more, fed by the snows and frozen mist of regions above the limits of perpetual frost. They stretch on 4,000 to 7,500 feet below the snow-line (limit of perpetual snow), because they have such magnitude that the heat of the summer season is not sufficient to melt them. Some of them reach down between green hills and blooming banks, into open cultivated valleys. The extremities of the glaciers of the Grindelwald and Chamouni valleys lie within a few hundred feet of the gardens and houses of the inhabitants. Each glacier is the source of a stream, made from the melting ice. The stream begins high in the mountains, from the waters that descend through the crevasses to the ground beneath; finally, it gushes forth from its crystal recesses, a full torrent, and hurries along over its stony bed down the valley.

2. *Glacier Regions.* — The best known of glacier regions is that of the Alps. West of the head-waters of the Rhone, the chain is divided into two nearly parallel ranges, a southern and a northern. The former includes, besides minor areas, two large glacier districts, — the

Mt. Blanc, and the Mt. Rosa or Zermatt district; and the latter, one of equal extent, though its peaks are less elevated, that of the Bernese Oberland. There is another district of glaciers at the head-waters of the Rhone, and others farther eastward.

Glaciers occur also in the Pyrenees, the mountains of Norway, Spitzbergen, Iceland, the Caucasus, the Himalayas, the southern extremity of the Andes, in Greenland, and on Antarctic lands. One of the Spitzbergen glaciers stretches eleven miles along the coast, and projects in icy cliffs 100 to 400 feet high. The great Humboldt glacier of Greenland, north of 79° 20′, has a breadth at foot, where it enters the sea, of forty-five miles; and this is but one among many about that icy land. Nordenskiöld states that passing toward the interior of Greenland, not a plant or stone or patch of earth is seen over the great ocean of ice and snow, 1,200 miles in extent from north to south and 400 miles in breadth. Some American glaciers are alluded to on page 536.

3. *Many Glaciers from one Glacier District.* — The following map (Fig. 1100) represents the Mt. Blanc glacier-region excepting a small part at its southwestern extremity from a manuscript map by Professor Guyot. The vale of Chamouni along the river Arve bounds it on the northwest, and the valley of the river Doire on the southeast. This mountainous area, though one vast field of snow, gives origin to numerous glaciers on its different sides, — each principal valley having its ice-stream. The series of dotted curves show the courses of the several glaciers. B is Mt. Blanc; *bs.*, the Glacier des Bois, or Bois Glacier (so named from a village near the foot of the glacier); *m*, the *Mer de Glace*, an upper portion of this glacier. The river Arveiron issues from the extremity of the glacier, and, after a short course, joins the Arve near the village of Chamouni. The glaciers "du Géant" (*g*), "du Talèfre" (*ta*), and "de Léchaud" (*l*), are the three largest of the upper glaciers which combine to form the *Mer de Glace*. The Glacier du Talèfre heads in two valleys; and at J, on the ridge between, is the Jardin, a spot with some verdure, often visited by travellers. The depth of the Mer de Glace is about 350 feet.

4. *General Appearance.* — Fig. 1105 is a reduced copy of a sketch in Agassiz' great work, representing the Glacier of Zermatt, or the Görner Glacier, in the Mt. Rosa region. This grand glacier receives some of its tributaries from the right, but the larger part from beyond the Riffelhorn, the near summit on the left. The dark bands on the glacier are lines of stones and earth, called *moraines*. The longitudinal lines on Fig. 1101 represent moraines on the Mer de Glace; the bands correspond to different tributaries of this glacier, and the broadest one to the right is that of the Géant Glacier. The ice of a glacier

is intersected by fractures or *crevasses*, made by its movement through the irregular valley.

Glaciers descend slopes of all angles; and, as with water or pitch,

Figs. 1100–1104.

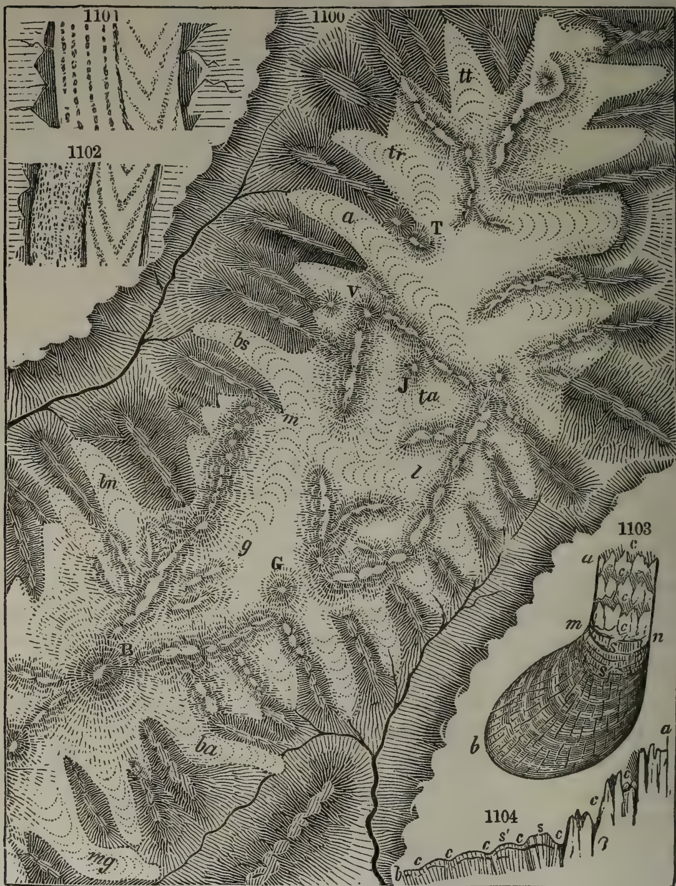
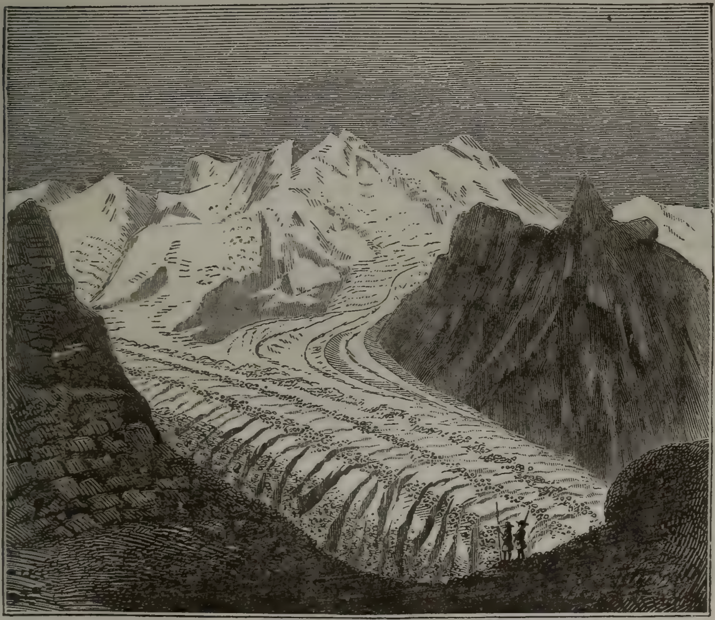


Fig. 1100. — Part of the glacier-district of Mt. Blanc, the lighter middle portion of the map sixteen miles long, out of twenty-two miles the whole length; river on the northwest side, the Arve in the valley of Chamouni, and that on the southeast side, the Doire; B, Mt. Blanc; G, Aiguille au Géant; J, the Jardin; T. Aig. du Tour; V, Aig. Verte; *a*, Argentière Glacier; *ba*, Brenva Gl.; *bn*, Bossons Gl.; *bs*, Bois Gl.; *g*, Géant or Tacul Gl.; *l*, Lechaud Gl.; *m*, Mer de Glace, upper part of the Bois Gl.; *mg*, Miage Gl.; *ta*, Talèfre Gl.; *tr*, Tour Gl.; *tt*, Trient Gl.

Fig. 1101. — Section of the Mer de Glace, near *m* of Fig. 1100, or opposite Trelaporte; 1102, section of same, near *bs* of Fig. 1100, or opposite Montauvert; 1103, View of the Rhone Glacier; 1104, profile of same, *c*, *c*, etc., being the transverse crevasses, fading out, and becoming curved after passing the cascade at *m n*.

will move over a horizontal surface, provided the supply of material is constant and sufficiently great. There are cataracts and cascades among them, as well as among rivers. One of the large tributaries of the Mer de Glace, the Glacier du Géant (*g*, Fig. 1100), descends in an immense ice-cascade from the plateau of the Col du Géant, over a vertical rock wall of the Tacul, into the valley below, making a plunge of 140 feet. The Glacier of the Rhone — one of the grandest in the Alps — is another ice-cataract. As the glacier commences its steep descent, it becomes broken across; and thus great sections of it plunge on in succession, separated partly by profound traverse chasms. Fig. 1103 gives the outline of the lower part of the glacier, *am* being the cataract, *mb*, its terminal portion or foot, from the extremity of which the river Rhone issues, and *c*, *c*, *c*, transverse crevasses of the cascade. The same is shown in profile in Fig. 1104, in which *c*, *c*, *c* are the transverse crevasses.

Fig. 1105.



The Görner Glacier.

The smaller and shorter valleys of the Alps, have also their accumulations of ice which break loose and at intervals descend the steep slopes or precipices, perhaps thousands of feet, in crashing *avalanches*, in which the ice is broken to fragments.

5. *Formation of Glaciers.* — The uppermost portion of a glacier consists of snow and frozen mist, deposited in successive portions, and usually more or less distinctly stratified. This part is called the *firn*, or *névé*. At a lower limit, the snow becomes compacted into ice, by pressure, owing to the depth of the accumulations; and here the true glacier-portion begins. Below the limit of perpetual frost there is occasional melting in summer, with alternate freezing; and this process aids in changing the mass, as well as the surface-snow, to ice. The stratification of the névé is not generally distinct in the icy glacier. In high latitudes, the ice increases in thickness through the frozen mists of the region and owing to this it often has a stratified structure. This feature was observed, and thus explained, by Wilkes, who found it characterizing the great ice-barrier of the Antarctic seas.

The following circumstances are essential to, or influence, the formation of glaciers.

(1.) The region must extend above the line of perpetual congelation.

(2.) Abundant moisture is as important as for rivers; and hence one side of a chain of mountains may have glaciers, while the opposite is bare. Abundant precipitation *in winter* especially favors their formation.

(3.) A difference of temperature and moisture between summer and winter is requisite; for otherwise the snows will be melted to the same line throughout the year, and will not descend much below the line of perpetual congelation.

The level of the snow-line, or that below which the snow annually precipitated melts away during the year, and the distance to which glaciers descend, depend mainly on the mean temperature and moisture of the region, and especially the mean temperature of summer as contrasted with that of winter. The height of the snow-line on the north side of the Alps is about 8,000 feet, and on the southern side about 8,800 feet. Below this limit, the glaciers descend 4,500 to 5,300 feet.

The snow-line in the Pyrenees is 8,950 feet above tide level; in the Caucasus, 10,000 to 11,000 feet; on the south side of the Himalayas, 12,980 feet, and on the north, 16,620 feet; at the equator, in the Andes, 15,980 feet; in Bolivia, 18,520 feet in the western Cordillera, and 15,920 in the eastern; in Mexico, 14,760 feet; in Chili, near Santiago, 12,780 feet; in Norway, 5,000 feet in its middle portion, and 2,300 feet at its northern extremity; in Kamchatka, 5,200 feet; in Alaska, 5,500 feet.

The lower limit of a glacier sometimes varies several miles, in the course of a series of years. A succession of moist years increases the thickness of the glacier, and thereby its tendency downward; while dry years have the reverse effect. If the moist years have also long, hot summers, the descent and lengthening of the glacier will be

further promoted, — since glaciers move most rapidly in summer. But hot, dry years would shorten it, by diminishing the ice, and especially at the lower end.

Lowering the mean temperature of a place, by cooling the summers, would lower the glacier-limit. Great Britain and Fuegia are in nearly the same latitude; and yet, in Fuegia, the snow-line is only 3,000 feet above the sea. If, by any means, the climate of Great Britain could be reduced to that of Fuegia, it would cover the Welsh and Irish mountains with glaciers that would reach the sea, the snow-line being but 1,000 to 2,000 feet above it; and the same cause would place the snow-line in the Alps at 5,000 to 6,000 feet above the sea, instead of 9,000. This change of temperature involves a removal of tropical sources of heat, or an increase of arctic sources of cold.

6. *The Law, Rate, and Method of Flow.* — The *law of flow* is essentially that of rivers.

(1.) The movement is most rapid at or near the middle line of the stream, because of friction along the sides. This is proved by the observation that a straight transverse line marked by poles set up in the ice ($a\,b$), becomes a curved line ($c\,d$) in consequence of the movement.

(2.) At a bend in the stream, the movement is more rapid on the convex side than on the concave; and the medial line of greatest rapidity is nearest the convex side.

(3.) When the stream abruptly narrows, the ice just above becomes more or less heaped, and slower in movement; and then it moves through the narrows below, with a consequently increased rate of flow.

(5.) The rate of movement of the glacier as a whole depends on the following conditions: —

(*a.*) The amount and rate of supply of moisture precipitated as snow.

(*b.*) The slope of the *upper surface* of the glacier: which slope is determined, in ordinary cases, partly by the supply of snow to the glacier, over its upper portions, and partly by the slope and form of the land beneath; but the latter slope is not a prerequisite to movement, as explained on page 535, just as it is not for the movement of water or pitch.

(*c.*) The presence or absence of obstructions, in the valley or region along which it moves.

All these points have been demonstrated by observation and experiment. The greater rapidity of the middle portion is shown by the fact that the transverse ridges made at an ice-cascade, like that of the Rhone, and the lines of earth and sand in the chasms, become afterward arched in front, as shown in Fig. 1103, in which the crevasses *c* are at first transverse, but curve below the cascade. The arch is sometimes very much elongated, almost to a triangular form, as in the

Géant portion of the Mer de Glace. This is well illustrated in Figs. 1101, 1102, from Tyndall: the right-hand half of the figure, corresponding to the Géant Glacier (the cascade which is alluded to on p. 678), has the transverse bands (carrying dirt and stones) elongated into triangles, while in the other half of the Mer de Glace there are no such bands, as the tributaries making it do not descend in cascades.

The view that the movement of glaciers was essentially like that of rivers or "softened wax" was announced by Bordier in 1773; and afterward more fully, with a specific recognition of the idea of plasticity in the ice, and of the influence, on the movement, of friction at bottom and along the sides, by Rendu, in a memoir read before the Academy of Sciences of Savoy, in 1841. Hugi, in 1827, built a hut on the Aar glacier, to determine its rate of motion; and found the movement 330 feet in three years, and 2,354 feet in nine years; and afterward Agassiz observed that in fourteen years it had moved 4,712 feet below its first position. Agassiz commenced in 1841 his grand series of observations on the Aar glacier, measuring the rate of movement in a section across the glacier; and, on July 4, 1842, his first results, proving the more rapid flow of the middle portion (his six poles in the line across having moved severally 160, 225, 269, 240, 210, and 120 feet), were published in the "Comptes Rendus." His investigations were continued for several years afterward; and in 1847 appeared his first great work, entitled "Système Glaciaire" Prof. Forbes visited Agassiz at his work on the Aar, in 1841, and in the summer of 1842 undertook an independent investigation on the Mer de Glace, near Chamouni; and in October of 1842 his measurements, confirming those of Agassiz, were published. A year afterward, in 1843, appeared his "Travels in the Alps," in which his various careful observations are given in detail, and the theory of glaciers, on the principle that the ice moves like a viscous fluid, is fully elucidated. His later writings on the subject are contained in a volume entitled "Occasional papers on the Theory of Glaciers." Later, Tyndall (from whom these historical notes are taken) made a further series of measurements and observations in the Alps, demonstrating the influence of bends in a glacier, and explaining other glacial phenomena. His views are contained in "The Glaciers of the Alps," 1860, and "The Forms of Water," 1872.

The rate of descent in the mass of a glacier varies from one or two inches, to over fifty a day; and the rate is about half less in winter than in summer. Ten to twenty inches a day in the warm season is most common; twelve inches corresponds to three hundred and sixty-five feet a year, or one mile in about fourteen and a half years. It takes the ice of the Col du Géant one hundred and twenty years to reach the lower end of the Mer de Glace.

Opposite Montanvert, where there is a bend in the stream, Tyndall found the movement per day, at eleven stakes, from the east to the west side, 20, 23, 29, 30, 34, 28, 25, 25, 18, 9 inches, the first and last being near the opposite sides. Descending from Trelaporte to Montanvert, the rate increases from twenty to thirty-four inches a day. At Trelaporte, the three tributary glaciers of the Col du Géant, Léchaud, and Talèfre have become one; and the ice moves in a channel but half as wide as the sum of the widths of these three tributaries. The rate of movement above this narrowing is hence slow; Tyndall found the movement per day, across the lower part of the Col du Géant, 11, 10, 12, 13, 12, 13, 11, 10, 9, 5 inches; across the lower part of the Léchaud glacier, 5, 8, 10, 9, 9, 8, 6, 9, 7, 6.

Forbes deduced, from his measurements, made at two stations on each of the Bois and Bossons Glaciers, the following results. The first station on the Bois Glacier was near

its upper part, where the rapidity is unusually great, and the other near its lower extremity.

	Bois I.	Bois II.	Boss. I.	Boss. II.
Motion from November, 1844, to November, 1845	847·5 ft.	220·8 ft.	657·8 ft.	489·1 ft.
Mean daily motion	27·8 in.	7·3 in.	21·6 in.	16·1 in.
Mean daily motion in summer, April to October	37·7 in.	9·9 in.	28·0 in.	22·2 in.
Mean daily motion in winter, October to April	19·1 in.	4·7 in.	15·8 in.	10·7 in.

The winter movement of the Mer de Glace is not over half that of the summer. Forbes found for the maximum in July, at his upper station on the Bois Glacier, 52·1 inches a day, and in December 11·5 inches.

(6.) The *capability of motion* in a glacier is attributed to —

(*a.*) A kind of plasticity in ice. Ice may be made, through simple pressure, to copy a seal or mould, like wax; or to take the form of a long cylinder, by pressing it through holes; and, if the ice, in such an experiment, is added in fragments, it comes out solid. The ice, when thus under pressure, is somewhat clouded, by the incipient fractures in it; but, when the pressure ceases, it is quite clear, owing to regelation along all such microscopic fractures. Kane mentions, in his "Arctic Explorations," the case of a table of ice, eight feet thick and twenty or more wide, supported only at the sides, which, between the middles of the months of March and May, became so deeply bent that the centre was depressed five feet. The temperature during the interval was at all times many degrees below the freezing-point.

(*b.*) The facility with which the ice breaks. It thus easily accommodates itself to new forms of surface. It also mends its fractures easily by a freezing together again of the surfaces in contact, — a process called *regelation*. On breaking a piece of ice and then pressing lightly the parts together again, the surfaces, if moist, will become firmly united. Having supported a block of ice at its two ends, if a fine wire is passed around it at middle and weighted below, the wire will slowly melt its way completely through the ice; but when the cut is completed, the mass will be as solid as at the outset, regelation having gone forward above the wire. The multitudes of fractures made in a glacier on steep slopes may all disappear where the motion becomes slow, and the ice feels the pressure from above.

The fragility of glacier-ice is owing not only to the brittleness of ice, but very largely (1) to the innumerable air-cells throughout the ice-mass, and (2) to the water which permeates it everywhere, especially during the warm season. Helland found the specific gravity of some Greenland glacier-ice to be only 0.866, owing to the air-cells within it. The air-cells are the occasion of melting about them during the

summer; and water is derived also from melting that takes place over the surface of the glacier. Another source of water is stated under *d.*

(*c.*) The capability of sliding along its bed, but only portions at a time.

(*d.*) Pressure lowers the freezing point of water, so that with increase of pressure, greater cold is required to keep ice solid; hence, wherever there is a strain occasioned by the obstacles to movement in a glacier, the ice melts, relieving the resistance and facilitating motion. (J. Thomson.)

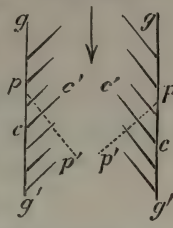
Rev. Henry Moseley, in a memoir on the cause of the descent of glaciers, treats of the *shearing force* of ice, or the resistance to disruption which proceeds from the cohesion of the mass; and he states, as the result of his trials with cylinders of ice having one end fixed, that the amount of force required for shearing one square inch of ice is about 75 pounds. He arrives, in his calculations, at the conclusion that a force exceeding 34 times the weight of the glacier is demanded to shear the ice and cause the rate of descent which Tyndall observed for the Mer de Glace at the Tacul. The results of his trials varied with the time allowed, 120 pounds being found to be required for a quick effect; and they did not recognize the variations in texture in the ice of a glacier. It has been questioned whether the shearing-force would not be wholly lost in case the time were given which an actual glacier takes. The deformations produced by even a small amount of pressure (see *a*, above) in slow processes, may be all the yielding that is needed; and this deformation is aided by the lowering of the freezing points by pressure, as urged by Professor James Thomson. With regard to the motion, Canon Moseley adopts the view that glaciers descend as a plate of lead descends a sloping surface, through alternate changes of temperature, the movement from expansion by heat being mainly downward because of gravity, and contraction working the same way. To this theory the obvious objection holds, as has been observed, that glaciers do not undergo the needed change of temperature.

Professor Croll, in his Climate and Time (and in earlier memoirs) accepts of Moseley's deduction as to the shearing force of ice, and brings forward a molecular theory to account for the motion of glaciers. He says: "We find that the heat applied to one side of a piece of ice will affect the thermal pile on the opposite side;" and explains this, not by radiation through the ice, but on the view that the heat applied passes from molecule to molecule through the mass; the transmission of the heat-energy conveyed by A to B melts B, but crystallizes A, and so it goes on through the ice. Professor Croll next observes that a molecule in the liquid state takes up about one tenth less space than in the solid, and hence, as it will obey gravity, it will move downward in the ice, and consequently crystallize at a lower position than it before occupied; and in crystallizing in its new position it will expand again. "All that the molecule requires is simply room or space to advance in." "Each molecule of the glacier consequently descends step by step as it melts and solidifies, and hence the glacier, considered as a mass, is in a state of constant motion downward." Gravitation is the source of motion; the expansion of the crystallizing molecule aids it; and the shearing-force is lost by the molecular melting. But it seems to be hardly probable that a glacier, hundreds of feet thick, could be thus urged forward. Any crevasse or crack would intercept the molecular transmission; and the cause would hardly have a chance to act in a crevassed glacier like the Mer de Glace. Professor Croll, however, explains the formation of crevasses on the same principle.

(7.) *Crevasses.* — Crevasses are made along the sides of a glacier, especially when passing prominent angles in the valley, or over places

of increased pitch. The ordinary direction is obliquely up stream, at an angle of forty to fifty degrees with the margin. As a glacier's movement is easiest and quickest toward its middle, owing to the friction either side, the lines of equal resistance to motion run obliquely up stream. Consequently the direction of the pull tending to produce fractures and crevasses (or that of greatest tension) is transverse to this; that is, obliquely toward the centre *down stream;* but Hopkins has shown that this pull ($p\ p'$) is strongest theoretically when it makes an angle of 45° with the sides ($g\ g'$, $g\ g'$) of the glacier, and this would give for the crevasses ($c\ c'$) a direction of 45° with the sides *up stream.* This angle would be modified by the form of the bottom, and by its pitch. Across the middle portions of a glacier, the movement often makes *transverse* crevasses, especially if there is much pitch — an extreme condition of which is shown in the Glacier of the Rhone, as already explained; and it may make none when it is uniform and the pitch is small. Forbes mentions one chasm 500 feet wide extending quite across the Mer de Glace. At a bend, crevasses form especially on the convex side of the stream, the ice undergoing a stretching on that side and a compression on the opposite. Through narrow passes in the valley, deep and irregular chasms are made; and then, on reaching a broader portion of the valley, the ice may return to a solid mass, with a comparatively even surface, having fractures only toward the sides.

Fig. 1106.



7. *Veined Structure.* — The ice of a glacier, as first observed by Guyot, is often vertically laminated parallel to its sides, and sometimes so delicately that the ice appears like a semi-transparent striped marble or agate. This is well seen either side of the middle portion of the Mer de Glace, and in the Brenva and Aar glaciers. The layers are alternations of cellular (or snowy) ice and clear bluish solid ice. The melting of the surface sometimes leaves the more solid layers projecting.

The structure is due, as shown by Tyndall, to the pressure to which the glacier is subjected in making its way between the walls of a valley, especially where there is a contraction in width, or a projecting point against which pressure is exerted, and particularly below a place of steep descent. It may be formed when two great glaciers unite, the pressure between the meeting streams being here the cause. In the lower part of the glacier of the Rhone, the laminated structure is produced, according to Tyndall, between the capes m and n (Fig. 1103, p. 690), — the *structure-mill*, in his language. It appears first in the section s, and is fully developed in the following one, s'. The radi-

ating lines in the view represent crevasses. The resistance to motion in a glacier is not continuously overcome, as in the case of a perfect fluid, but intermittently. This is evinced in the *successive* transverse crevasses of a cascade-glacier, like that of the Rhone, or in the dirt-bands which are registers of the successive crevassing. Each movement, moreover, must cause a series of vibrations, of great force, in the ice. Such intermittent action is especially calculated to produce a laminated structure. As Tyndall has observed, the air-cells appear to have been in part expelled from the bluish layers by the pressure, and in part to have been obliterated by an incipient liquefaction and refreezing of the layer. The cause is the same that has produced slaty cleavage in some fine-grained rocks.

II. Transportation and Erosion.

1. *Transportation.* — The *moraines* of glaciers are made from (1) the stones and earth which fall from the cliffs along their borders; (2) the material received from falling avalanches; (3) that which is taken up by the ice from the surface of the valley against which it moves. They form in all the stages of a glacier's progress though smallest in the region of the *névé*, where the area of bare peaks is usually small, compared with the extent of snow.

From their mode of origin, it follows that moraines are situated primarily along the margin of a glacier. But, when two glaciers coalesce, the two uniting sides join their moraines in one; and this one is remote from the borders, and may be central — as in the glacier of the Aar — if the two coalescing streams are about equal. It follows from the above that the number of moraines on a glacier can never exceed the number of coalesced glaciers by more than one. An isolated peak rising above a glacier may send off its stones and earth all in a single line or moraine.

The nearest moraine, in the view of the Glacier of Zermatt on page 691, is that of the Riffelhorn; the second is a union of moraines of the Görnerhorn and Porte Blanche; the third, a union of two moraines from two Mt. Rosa Glaciers; the fourth, the great moraine of the Breithorn, the summit in the middle of the view. Other moraines may be seen in the distant part of the glacier. In Fig. 1101, on page 690, representing a section of the Bois Glacier near Trelaporte, there are six distinct moraines.

Toward the lower extremity of a glacier, the several moraines usually lose their distinctness, through the melting of the ice; for this brings the stones and earth that were distributed at different depths to one level, and thus produces a coalescence of the whole over the surface.

The stones are both angular and rounded ; the former are the more abundant in the Alps, and the latter about the much larger Greenland glaciers. Many are of great magnitude. One is mentioned, containing over 200,000 cubic feet, or equal in size to a building one hundred feet long, fifty wide, and forty high. As the large masses shade the ice below from the sun, and so protect it from melting, they are often left capping a column of ice.

At the glacier of the Aar, the central moraine is raised 100 to 140 feet above the general surface either side ; but this is partly owing to the pressing up of the ice itself, by the mutual pushing of the two combined glaciers of which it is made. The breadth where narrowest is 250 feet; and from this it increases to 750 feet, half-way to the termination of the glacier, and to treble this below.

The final melting of a glacier leaves vast piles of unstratified, or imperfectly stratified, stones and earth toward and about its lower extremity. The stream which proceeds from the glacier works over all that comes within its reach, abrading it and carrying it onward down the valley, and making deposits on its banks which are more or less perfectly stratified.

2. *Erosion.* — A glacier depends for its power of erosion on the pressure of the mass, its rate of motion, and the stones it carries in its bottom and sides. The pressure per 100 feet of thickness for glacier ice is about 40 lbs. to the square inch, or, for a thickness of 500 feet, 200 lbs. It also erodes indirectly through its sub-glacial stream.

(1.) Through the wrenching the ice undergoes, transported rocks or stones have their angles more or less blunted or rounded by mutual attrition, and a general grinding of the earthy material takes place.

(2.) The stones, large and small, in the bottom and sides of a glacier make it a tool of vast power as well as magnitude, for scratching, ploughing, and planing the rocks against or over which it moves. Besides this, it pushes along gravel and stones between itself and the rocks, with the same kind of effect. The rocky cliffs and ledges in the vicinity of the glaciers are in many places furrowed, planed, and rounded, over their whole exposed surfaces ; and the abrading stones are also smoothed and scratched.

The rounded knolls of rock along the track of a glacier have been called *sheep-backs* (*roches moutonnees*) in allusion to their forms. They are a prominent feature of all glacial regions ; and those of the Glacial period (p. 531), when they were formed over a vast extent of country, are sometimes preserved to the present time in great perfection. The view on the following page (Fig. 1107), from a photograph obtained by the expedition under Dr. Hayden in 1873, represents a portion of a great crouching flock of them, extending for 2,000 feet along

a valley leading down from the "Mountain of the Holy Cross," one of the prominent summits (12,485 feet high) in the mountains of Colorado.

The thickness of the ice in the Alps nowhere exceeds 500 feet. Let it be 2,000 feet, as now in some Greenland glaciers, or twice this, as in many regions during the Glacier period, and the work of erosion accomplished would be vastly greater, since it is directly proportioned to the thickness.

(3.) The grinding of the stones against one another, and those of the bottom against the underlying rocks, produces very fine powder,

Fig. 1107.

View on Roche-Moutonnée Creek, a tributary of Eagle River, Colorado.

which makes the waters of the underflowing stream milky, and forms clay-like deposits, of which the bowlder clay of Drift regions is an example.

(4.) The glacier finds the rocks beneath usually jointed, laminated, or foliated, or in upturned beds, and it thus has an opportunity to tear off masses. This is in fact its most efficient means of erosion; for hard rocks which might require a century for a foot of direct wear, may, through the natural divisional planes, yield by scores of yards in the same period.

(5.) The *subglacial streams*, one of the prominent features of a glacial region, and their continuation down the mountain valleys, are also

a very important means of erosion. They swell by the summer melting, and become violent, plunging torrents, and thus produce great and rapid work while the glacier is slowly creeping along. The larger part of the erosion of valleys along the courses of glaciers has been performed by these streams. The snow and ice of Alpine valleys often cause, indirectly, violent erosion and transportation of material, by damming up streams. In no other way can barriers be thrown so readily across profound valleys; and the deluges caused by the accumulated waters, when they break loose, are often very destructive. The Alps are full of examples. Again, the valleys are sometimes dammed up by great moraines, making lakes; and such lakes sometimes break through their barriers, and flood the valley below with tearing waters.

A glacier sometimes acts as a dam against the sides of a valley, and forces a stream to flow far above its natural level. On the Aletsch glacier, a lake which was thus made, and had existed for a number of years, was recently discharged beneath the ice. By such a method of damming all the effects of river action, such as erosion and alluvial and flood deposits, may be made in a glacial region far above the level of natural drainage.

4. Icebergs.

A glacier on a sea-coast often stretches out its icy foot into the ocean; and, when this part is finally broken off, by the movement of the sea, or otherwise, it becomes an iceberg. Greenland is the great region of icebergs, no less than of glaciers. They carry away the stones and earth with which the glacier was covered during its land-progress, and transport them often to distant regions, whither they are borne by the polar oceanic currents.

Dr. Kane describes the great pack of icebergs that occupies the centre of Baffin's Bay, and mentions that some were 300 feet high, and large numbers over 200 feet. There were 280 icebergs of the first magnitude (the most of them over 250 feet) in sight at one time.

In the Antarctic, the long ice barrier observed by Captain Wilkes had a height above the sea of 150 to 200 feet; and some of the bergs were 300 feet high.

As the specific gravity of ice is 0·918 (at 32° F.), the proportion in weight of the mass out of water is about *one twelfth.*

The icebergs of the Atlantic melt mostly about the Banks of Newfoundland, or between the meridians of 44° and 52°. They have been observed in this occean as far south as 36° 10′.

Icebergs are (1) a means of transporting stones and earth from one region to another (see p. 534). (2) When grounded on rocks, they

may scratch the surface; but closely-crowded and regular scratches like those of glaciers, over large areas, could hardly be made. The currents of Baffin's Bay flow southward on the west side, and northward on the other, — which would give great irregularity there to the scratches of grounded bergs. An iceberg "rocked by the swell of the sea, and sometimes turning over," could not be good at scoring submerged rocks. Moreover, these rocks, in the seas in which icebergs melt and drop their freight of stones, would seldom be uncovered.

The more important works and memoirs on glaciers are the following: —

Agassiz: Études sur les Glaciers, 8vo, Neuchatel, 1840. — Système Glaciaire, Nouvelles Études et Expériences sur les Glaciers Actuels, 8vo, with an Atlas of 3 maps and 9 plates, Paris, 1847.

J. De Charpentier: Essai sur les Glaciers et sur le Terrain Erratique du Bassin du Rhone, 8vo, Lausanne, 1841.

J. D. Forbes: Travels in the Alps of Savoy, etc., 8vo, Edinburgh, 1843. — Occasional Papers on the Theory of Glaciers, 8vo, Edinburgh, 1859.

J. Tyndall: The Glaciers of the Alps, 8vo, London (and Boston), 1861. — The Forms of Water (in Appleton's International Series), 8vo, New York, 1872.

Rev. Henry Moseley: Proc. Roy. Soc., xvii., 202, 1869.

James Croll: Climate and Time, 8vo, London, 1875.

James Geikie: The Great Ice Age, London, 1877 (2d ed.).

Dollfuss-Ausset: Matériaux pour l'Étude des Glaciers, 8 vols., 1864–70.

The following relate to existing glaciers of the Pacific Coast of North America: —

Davidson, on the first discovery of glaciers on the Pacific Coast (on Mt. Rainier, Mt. Baker), Proc. Acad. California, iv., 161, 1871, and Am. J. Sci., III. iv., 156, 1872. Clarence King: Glaciers of the Pacific Coast (on Mt. Shasta, Mt. Hood, Mt. Rainier, etc.), Am. J. Sci., III. i., 157, 1871, and Report 40th Parallel, vol. i., 462, 1878. John Muir: Glaciers in California (Sierra Nevada), Overland Monthly, Dec., 1872. Joseph Le Conte: Ancient Glaciers of the Sierra Nevada (with notice of existing), Amer. J. Sci., III. v., 325, x., 126, xviii., 43, 44. Professor LeConte calls the imperfect "Glaciers" noticed by Muir and himself in the Sierra Nevada, *Glacierets*.

4. WATER AS A CHEMICAL AGENT.

Water does its chemical work among the rocks, —

(1.) Through its capacities as water.

(2.) Through the affinities of its elements, directly.

(3.) By means of the substances it takes into solution.

This work is either *destructive* or *formative*. The air aids largely in the results, and hence its chemical effects are here in part included.

I. DESTRUCTIVE WORK.

1. Through its Capacities as Water.

1. *At the ordinary Temperature.* — It takes 50,000 parts of pure water, at the ordinary temperature, to dissolve one part of calcite or carbonate of lime: over 200,000 for one of a silicate of alumina;

7,500 for one of silica in its gelatinous condition; 460 for one of sulphate of lime, or gypsum. With heated water, the amount for sulphate of lime is the same.

With the exception of gypseous rocks, there is consequently no appreciable erosion, through the action of *pure* water; but these are rapidly worn away.

Many minerals tend to combine with water, and thus become altered in constitution.

Anhydrite, or anhydrous sulphate of lime, changes to gypsum, or hydrous sulphate of lime; and great beds of the latter mineral have been made out of the former. Mica and many other minerals often take in two or three per cent. of water, through incipient change. Feldspar, according to Hunt, may owe its decomposition and change to porcelain clay, or kaolin, to a tendency to combine with water. In most of these cases of hydration, carbonic acid has accompanied the action of the infiltrating waters, and has been essential to the process.

2. *At an elevated Temperature.* — Water at high temperatures, especially above the boiling point, as superheated vapor, has great dissolving and destroying power. No silicate will withstand it. The feldspars, the most universal of silicates, yield before it with great facility. It takes the alkalies, and also the silica, making the siliceous waters of most hot-spring regions. At the present time, the disaggregation of rocks going on by this means is small; but in all regions of metamorphism, this has been a prominent source of the changes.

2. Through the Elements of Water directly.

Water consists of oxygen and hydrogen, in the proportion, by weight, of 8 O to 1 H. The oxygen is the element of chief importance. But water has acted conjointly with atmospheric air in these changes, and the latter is often the source of the oxygen; the carbonic acid of the air (p. 51) gives aid, as explained on page 706. Water alone usually protects the rocks it covers.

A. Oxydation at the Ordinary Temperature. — The tendency of iron to oxydize is a prominent source of rock-destruction, and thereby of soil-making and gravel-making. In the change, the iron passes to the sesquioxyd state; and it either remains *anhydrous*, in which case the powder is *red*, and the material is *hematite* (p. 59); or it becomes *hydrous*, has then a *brownish-yellow* powder, and is the mineral *limonite*.

The most common minerals undergoing the change are: (1) The sulphids, pyrite and pyrrhotite (p. 59); (2) carbonate of iron, and any calcareous carbonate containing iron; (3) silicates in which iron is present in the protoxyd state, especially pyroxene (augite), hornblende, black mica, and chrysolite.

1. *The Sulphids of Iron.* — The oxydation of these sulphids is one of the most universal means of rock destruction; for there are few rocks that do not contain pyrite, in disseminated grains or crystals; and only the firmer and smaller crystals of pyrite withstand the tendency to change. Under the combined influence of moisture and the atmosphere, both the iron and sulphur undergo oxydation, and often produce sulphate of iron; or, if bases are at hand, like lime, or alkalies and alumina, the acid takes the lime to make sulphate of lime, or the alkalies and alumina to make alum; and the iron, thus left free, becomes a sesquioxyd, and usually the hydrous sesquioxyd, or limonite. Thus the decomposition is doubly destructive. Whenever taking place in a granular rock, the oxyd, becoming distributed among the grains, tends to pry them apart, and so disaggregate the rock; while the acid aids in decomposing the other ingredients present.

2. *Carbonates containing Iron.* — Carbonate of iron is the ore of iron called *siderite* or *spathic iron.* Under exposure to air and moisture, the iron, which the mineral contains in the protoxyd state, undergoes oxydation, becoming brown, and changing to limonite. The alteration goes on rapidly, to the depth that water and air succeed in penetrating. Any rock, through which this carbonate is distributed, will undergo rapid alteration and destruction at surface. A ferriferous carbonate of lime, or carbonate of lime and magnesia (in which iron replaces part of the calcium or magnesium), undergoes the same kind of destruction, though less rapidly. The rock often becomes reduced to a bed of more or less pure limonite. Crystalline limestones usually undergo this change more readily than common massive limestone, because more permeable to moisture.

3. *Other Cases of Oxydation.* — The oxydation of *carbon, hydrogen,* and other ingredients of vegetable and animal matter, is another important means of geological change, through the oxygen of water and air. The fallen unburied leaves and stems of the forest have their carbon changed by this means to carbonic acid, and so, in a true sense, consumed; and if buried, the air being to a great extent excluded, part of the carbon will be preserved to make coal, while other portions will be lost by this sort of combustion (p. 363). Animal matters are subject to an analogous change.

Again: Oxydation takes place through the agency of microscopic plants. The decay of animal and vegetable matter is a process of oxydation. But it never begins except through the presence and agency of certain kinds of vegetable organisms (*Bacteria,* and the like) whose germs exist everywhere in the air; for it has been found by experiment that the complete exclusion of these organisms prevents putrefaction from taking place.

Besides producing the oxydation of decay (and also that of ordinary fermentation) microscopic plants, but of a different kind, oxydize the nitrogen of the atmosphere and make nitrates. These organisms live in dark places, and hence it is that nitrates, the source of saltpetre, (as calcium nitrate,) form in the earthy floors of caverns or covered places. The process (called *nitrification*) often slowly erodes or disintegrates the rocks of the cavern, since the nitric acid may take from these rocks the lime or other ingredient with which it enters into combination.

B. Combinations of the Hydrogen of Water, at the Ordinary Temperature. —When pyrite is undergoing oxydation, through the decomposition of water, the hydrogen of the decomposed water will form sulphid of hydrogen with the sulphur, and so give origin to "sulphur springs." This sulphid of such springs may also become oxydized, the sulphur making with the oxygen *sulphuric acid*, and the hydrogen producing *water*, and thus may be produced *sulphuric acid springs;* though this acid is so strong in its affinities that it seldom is allowed to remain free.

C. Effects at an Elevated Temperature. — In volcanoes, the vapors of water, in connection with sulphur vapors from sulphids, give origin to sulphurous acid or sulphuretted hydrogen; and the acid is destructive to the volcanic rocks within its reach.

D. Effects through the Dissociated Elements of Water. — At temperatures about 1800° F., the elements of water are separated. In the process of metamorphism, this temperature has, beyond doubt, been sometimes concerned. But, as the moisture present was under high pressure, and pressure raises the temperature of dissociation, it is not certain that this means of change has been an actual one, at least since the earth's crust was first formed.

3. Destructive Effects through or by the aid of Substances held in Solution in Water.

A. Carbonic Acid. — The most important agent of destruction, as well as of construction, among the substances dissolved in water, is carbonic acid gas; and it starts for its work mostly from the atmosphere, although constituting but four parts in 10,000 of air. In Archæan time, as stated on page 156, its effects were far greater than now, owing to the much larger proportion of carbonic acid in the atmosphere; and from that time they have gradually diminished. It is carried from the air to the earth's rocky surface in all precipitated moisture, and is consequently present in all streams, lakes, and oceans. Other prominent sources of this gas in the earth's waters, and in the soil, are: (1) the respiration of aquatic and underground animals, carbonic acid constituting a large part of the air exhaled; (2) vegetable and animal decomposition, carbonic acid being an ultimate product, as it is of the combustion of coal; (3) chemical agents (mentioned beyond), separating carbonic acid from carbonate of lime.

1. *Eroding Action.* — Carbonic acid has a strong affinity for potash, soda, lime, magnesia, and iron. If waters containing carbonic acid are made to pass through powdered feldspar, mica, hornblende, pyroxene, limestone, and other mineral materials containing these substances, portions of them will be taken up and carried off; and the disorganization thus begun is attended by a loss also of silica and alumina, and ends in the destruction of the rock made of these minerals, so far as it is subjected to the process. Professors W. B. and R. E. Rogers found, in their experiments on the action of carbonated waters, 0·4 to one per cent. of the whole mass under digestion dissolved away in only forty-eight hours.[1]

[1] *American Journal of Science*, II., v., 401.

Some granites and gneisses are decomposed to a depth of fifty or sixty feet; and in tropical countries, like Brazil, where a warm climate favors activity in nature's chemistry, and no glacial agent has worn off the earthy surface of the country, the depth of altered rock, according to Liais, is sometimes *a hundred yards.* The decomposition has been attributed mainly to atmospheric carbonic acid and moisture, and to a great extent by the process just pointed out. The decomposition of the sulphids of iron, when present, would also aid in the destruction.

Limestones are worn, through the same atmospheric agents. Waters containing carbonic acid will dissolve readily carbonate of lime, making of it the soluble *bicarbonate of lime;* 1,000 parts of such water taking up one of carbonate of lime. Carbonic acid from other sources aids in this work, and especially in the case of limestones; that produced within the soil is an important contribution to underground waters, and a means thereby of making caverns in limestone formations.

2. *By preparing the way for Oxydation.* — Carbonic acid helps on destruction, also, by giving iron a chance to oxydize. On dissolving out the iron from an iron-bearing mineral, in the manner above explained, it forms with this iron carbonate of iron; and then immediately the oxydation of this carbonate of iron goes forward, as already stated, and with the same result. This process, on the part of carbonic acid, of robbing minerals of their iron, and then the next instant losing the iron by its becoming an oxyd, is usually going on more or less slowly, whenever rocks containing these iron-bearing minerals are accessible to air and moisture. The action of the carbonic acid cannot be perceived; but the oxydation of the iron, the secondary result, is very manifest in the brownish or reddish color which the exposed rock acquires, and also in its disaggregation. In the case of a close-textured rock, like much doleryte (trap), the change gradually extends from the surface inward, making a discolored crust. This crust loses at surface at the same rate that it progresses inward; and hence its thickness, for a given variety of rock, is nearly uniform.

B. Organic Acids. — The work here attributed to carbonic acid is also performed, though to a less extent, by *organic acids,* made from vegetable or animal decomposition. They contribute to the solution and erosion of limestones, and also to the process of oxydation.

C. Silica. — Silica is present, in minute traces, in most natural waters. 7,500 parts of water will dissolve one part of silica in the gelatinous or soluble state; and the shells of Diatoms, which are present over the bottoms of most waters, are silica in this soluble state.

If the waters are at all alkaline, the proportion of silica that may be taken up is much larger.

The geological effects of the silica of *cold* solutions appear to be of only infinitesimal importance; while the siliceous solutions made by heated waters, like those of geyser and other hot-spring regions, have great destroying power, though at the present time confined to small areas. They act on limestones, expelling carbonic acid, and making silicates containing lime; and this is probably a prominent source of the carbonic acid gas given out in some solfataras, and also of that which has made the region of Yellowstone Park as remarkable for its calcareous as for its siliceous waters.

D. Sulphuric Acid and Soluble Sulphates. — Waters holding in solution sulphuric acid or soluble sulphates (alums, vitriols, etc., made through the decomposition of sulphids), act erosively on most rocks within reach, and especially on limestones.

II. FORMATIVE WORK.

The destructive work in geology is all preparatory to new formations.

1. *Through Calcareous Waters.* — The carbonate of lime taken up by carbonated waters, making them calcareous, is the means by which limestones have been consolidated; even sea-water contains enough carbonic acid to take up some carbonate of lime. The calcareous sands of a beach washed over by the tides, and thereby alternately wet and dry, become coated with a deposit of carbonate of lime from the waters; and finally all are united into a solid mass. Sands and pebbles of other kinds are treated in the same way; and, on shores bordered by coral reefs, the pebbles of basalt, and other kinds, often have a milky exterior, from a film of carbonate of lime.

The calcareous mud and sand of the reef under water become solidified apparently without other means than the carbonated sea-waters.

Beds of limestone are sometimes made by depositions from calcareous waters, though small beds, compared with those of organic origin. The *travertine* of Tivoli, near Rome, is a large deposit along the Anio (p. 69), whose waters are there strongly calcareous. On the banks of Gardiner's River, in the region of the Yellowstone Park, in the Rocky Mountains, thick limestone deposits have been made, from the waters of numerous and large hot springs and geysers, as well illustrated and described in the Reports of Dr. Hayden. The calcareous waters, in descending the slopes of the hills, have made a series of parapets at different levels, inclosing basins, over which the water drips or plunges on its way to the bottom, as illustrated in the

sketch below, from a photograph by W. H. Jackson. Travertine is throughout concretionary, and in many parts cavernous, and commonly wholly unlike the even-grained material of ordinary limestone strata. Leaves, stems, and nuts are often *petrified* by the calcareous waters.

The waters dripping into limestone caverns produce, by their calcareous depositions, the pendent stalactites of the roof of the cavern, and the stalagmite of the floor. The stalagmite shows, in a cross fracture, the fact of its gradual deposition, by the bandings in its colors. The deposit from such waters sometimes has a soft chalky texture.

Fig. 1108.

Travertine deposits on Gardiner's River.

Some sand and clay beds owe their consolidation to carbonate of lime derived from the remains of shells present in them.

2. *Through Siliceous Waters.* — Siliceous waters have done far the larger part of the consolidation of sandstones, conglomerates and clay beds. The silica has commonly been taken up from feldspars distributed throughout the rock itself, or from the siliceous relics of Diatoms and Sponges present in it, by the heat and moisture penetrating it; and then consolidation has taken place as the temperature lowered. Such solutions have filled fissures and cavities in rocks with quartz, making quartz seams and veins. They have also been one means by which mineral silicates have been formed in the process of metamorphism (p. 760).

They have also produced extensive deposits of silica in regions of hot springs, remarkable examples of which occur in the Yellowstone Park, and also in Iceland and New Zealand. The silica in these deposits is mostly in the state of common opal. When the depositions cease, from the failure of the hot waters, much of the material soon crumbles, and loses its peculiar external features.

Wood, shells, and insects, are often petrified by such siliceous waters, so that silicified stumps are common over large portions of the Pacific slope, one of the most remarkable regions of igneous eruption in the world. Portions of trunks of more than a hundred silicified trees, one of them twelve feet in diameter, lie prostrate together, according to Marsh, in a thick bed of tufa, about five miles southwest of Calistoga Hot Springs, in the Coast Range, north of San Francisco, California — a locality first made known by C. H. Denison. The trees are described as probably all Conifers. They received the silica from the tufaceous deposit, and probably while it was penetrated by heat and moisture, if not comprised within the range of true hot springs; and the tufa had its origin in a shower of volcanic cinders (from some unascertained vent) settling down over the forest region.

Siliceous solutions have moreover silicified the fossils of many of the earth's limestones and other strata, and made flint or hornstone nodules in them, though without silicifying the limestone itself.

The most of the above results have been produced by hot, or at least warm, solutions. But, in the case of the fossils and hornstone in limestones, — of which the chalk affords an example, — even a low heat could hardly have been necessary. The silica was distributed through the calcareous mud of the sea bottom, in the form of Diatoms, Polycystines, and siliceous spicules of Sponges, and therefore was in the soluble state; and the solution of this silica took place within the mass of the deposit. The tendency of matter of one kind to concrete together led to the forming of flint-nodules and the silicifying of shells and other foreign substances.

3. *Through Oxydation.* — The oxydation of the iron of ferriferous minerals, in the destruction of rocks described above, is also a formative process. It usually results, as has been stated, in making the brown hydrous oxyd, limonite, unless either the climate is a dry one, or the temperature is near or above the boiling point, when the red oxyd, hematite, is formed. Further, accumulations of iron ores in great beds have been thus made. Carbonates containing iron and sulphids of iron have been the chief sources of the ore; but, where these were present to start the process, all other iron-bearing minerals at hand have contributed to the end.

In a large number of cases, the rock has decomposed and left the

bed of iron ore — mostly limonite — in its place. This is the fact in the region of Lower Silurian schists of the Green Mountains, as first explained by Percival, and of their continuation in New Jersey, Pennsylvania, Virginia, Tennessee, Georgia and Alabama. The lamination of the schist may be sometimes detected in the ore bed, when its minerals have disappeared. In one of the mines of Richmond, Mass. (the Leete ore-bed), it is apparent that the source of the iron was mainly a ferriferous carbonate. A high limestone ledge stands just along-side of the mine, to the north; and, within the deep and large excavation, in the midst of the ore, there are some few beds of very compact gray carbonate of iron still remaining, which are conformable or nearly so in dip with those of the limestone ledge a hundred yards off. The rock from which the limonite originated was probably, therefore, this carbonate; possibly, portions of it that were less compact or more permeable to moisture.

The iron of exposed rocks undergoing decomposition is very commonly washed out of them into low places or marshes, and there deposited, making beds of cellular limonite, called "bog iron ore." Such beds often contain nuts and leaves, petrified by the oxyd of iron. The iron, when carried by the waters, is in solution as bicarbonate, or combined with organic acids derived from the soil. The change to limonite takes place where the waters have a chance to stand and evaporate. In this way, vast beds of ore have been made, even those of Archæan time (p. 153). The beds made in marshes are in general less pure than those formed in place, because a marsh gathers much dead animal matter, and therefore the ore usually contains phosphates (p. 59). Even much of the Archæan ore contains phosphate of lime (apatite) in visible grains.

The oxydation of iron has also taken place without any attending destruction of rocks. In the Marquette iron region, and others, there are imbedded octahedrons of iron ore, which are now hematite Fe^2O^3, or, what is the same, $FeO^{\frac{3}{2}}$, but which were originally magnetite, $FeO^{\frac{4}{3}}$, as is proved by their having the crystalline form of magnetite, instead of that of hematite. They show that the great bed of ore, of which they are a part, has been in some way oxydized (receiving in it a sixth more of oxygen). This was probably done through the aid of the moisture penetrating the whole, when at a high temperature. Igneous rocks usually contain magnetite rather than hematite.

Consolidation of rocks is another effect, in some cases, of the production of iron ore. Limonite becomes distributed among pebbles, and thereby makes an ironstone conglomerate.

The waters, filtering through soil and gravel, often take up enough oxyd of iron to cement a bed of pebbles lying, at a lower level, on another layer sufficiently close in texture to hold the water and give the iron a chance to deposit; and this is one way in which what is called *hard-pan* is sometimes made. The underlying impervious bed is

not absolutely necessary to the result, although promoting it. The pebbles wet with the ferruginous waters, when they dry, in times of drought, take a deposit of iron; and this process may end in complete consolidation.

When a low degree of heat is concerned in the consolidation of beds of sand, containing iron-bearing minerals in grains, the *red* oxyd of iron is usually produced, reddening the rock, and acting also in some degree as a cement for the sand; the same heat, however, often leads to the production of a solution of silica, which aids in the consolidation.

The fumes of chlorid of iron from a volcanic fumarole, in contact with water in vapor, give up the chlorine to the hydrogen of the vapor (making hydrochloric acid), and the iron to the oxygen of the same, making oxyd of iron, or hematite. In this way, crystallized hematite is sometimes formed in scorias about a fumarole. But according to Palmieri, this is not the only or common way. Iron exists in the liquid lava, in the state of magnetite; and the oxydation of magnetite may be the more common method.

4. *Through Decomposition of Feldspars.* — Feldspars change to kaolin (the clay of which porcelain is made), on decomposition, losing the alkalies and part of the silica, and taking in water; so that feldspar, consisting of one part atomically of alkali, one part of alumina, and three to six parts of silica, becomes reduced to one of alumina, two of silica, and two of water (or kaolin). Thus the large beds of kaolin have been made, and larger beds of clay slate free from alkalies.

5. *Through the Action of Sulphuric Acid.* — Limestone (carbonate of lime) is changed to sulphate of lime by sulphuric acid; and thus beds of gypsum and anhydrite have been formed. The sulphuric acid may come directly from the decomposition of sulphids; or from the oxydation of sulphid of hydrogen or of sulphurous acid, in volcanic regions. Alumstone (sulphate of alumina) and alum efflorescences (sulphates of alumina and the alkalies, or magnesia, or iron) are often produced when alumina is present. Different sulphates of iron, or vitriols, and some related products are other results.

6. *By Deoxydation.* — Organic matters, owing to their tendency to oxydation, may take oxygen from sesquioxyds, and make protoxyds of them; so that carbonic acid, if at hand, can combine with the iron, and form carbonate or bicarbonate; and organic acids, as Hunt has urged, may form soluble organic compounds. In the decomposition of a rock containing feldspars, in which iron is present, the clay, when first made, is usually colored; but after the bed of clay has thickened to a few inches or feet, it is often found that the oxyd of iron has all been washed out, leaving it nearly or quite white. This is accomplished by the process of deoxydation just mentioned. By means of it also, large beds of carbonate of iron have sometimes been formed.

In a similar way, sulphates have been reduced to sulphids. In the black marsh-mud deposit of the Quaternary of Louisiana, there is some pyrite, derived through the deoxydizing process of organic matters. (Hilgard.)

7. *Through the Evaporation of Sea-water, and attendant Chemical Changes.* — The ocean is a mineral spring that dates from the period

in the earth's history when the vapors first settled on the cooling crust. All the materials that were at all soluble, and that the conflict of hot rocks and hot waters could have then made, were at first present in it. An excess of phosphates and of carbonate of lime continued to characterize it after the Paleozoic era had begun, as is learned from the abundance of *Lingulæ* and other phosphatic shells (pages 59, 593), and the profusion of other shells, and of corals. At present, and since Paleozoic time began, the only chemical deposits abundantly made from the waters, in confined basins where evaporation was possible, appear to have been *gypsum* and *common salt*. But, with these, some magnesian minerals have been produced, and also some deposits of borates. Salt deposits are now in progress, in confined salt-water basins, along-side of low seashores.

In the preceding pages on water as a chemical agent, only the more prominent and obvious of the results have been considered. All the ingredients of mineral springs have done work, in the way both of destruction and of construction. A full discussion of the effects belongs only to a treatise on chemical geology.

V. HEAT.

The effects of heat here considered are those connected with the making and modifying of the earth's rocks, strata, and life, exclusive of the comprehensive changes resulting from the earth's gradual refrigeration. They include (1) expansion and contraction; (2) fusion, solidification, and attending igneous phenomena; (3) metamorphism and vein-making, besides chemical depositions and changes. After some observations on (1) the Sources of Heat, these subjects are considered under the following heads: (2) Expansion and Contraction; (3) Igneous Action and Results; (4) Metamorphism; (5) Mineral Veins.

The effects here referred to are mostly due to heat above the ordinary temperature. But some geological changes of the widest influence have been carried forward by simple changes in climate. Hence, all sources of change in temperature, however slight, have a geological interest.

The chief causes influencing the *distribution of heat* over the globe require a brief notice before proceeding to the subject of the sources of heat. The means of distribution are chiefly oceanic currents and the winds; and the distribution of the land of the globe determines partly the heat the air receives, and the directions the currents of the ocean take. These points are illustrated on pages 38 to 44.

The effect of the Gulf Stream on the Arctic and North European

climates has been elucidated by the calculations of Mr. James Croll. His conclusion is, that the amount of heat conveyed from the equatorial regions northward in the Atlantic by this stream is equivalent to 77,479,650,000,000,000,000 foot-pounds of energy per day, which is equal to all the heat received by 1,560,935 square miles at the equator, and more heat than is conveyed by all the aerial currents; and that the stoppage or diversion of the current would diminish to this extent the heat of the Arctic seas and North Atlantic. (Croll's Climate and Time, p. 25.)

It has been supposed that the diversion of the Gulf Stream from the North Atlantic may have taken place through the sinking of the region of the Straits of Darien; but there is no sufficient evidence that such a diversion has happened since Mesozoic time, if it did before. A more reasonable hypothesis is that it may have been accomplished by a raising of the sea-bottom nearly to the surface between Scandinavia, Great Britain, Iceland, and Greenland, where the depth now is mostly less than 100 fathoms and nowhere exceeds 1,000, and along one tract, is not over 500 fathoms. The effect of such a North Atlantic barrier would be to confine the Gulf Stream circuit to the North Atlantic, and thereby to increase the temperature and amount of evaporation of that ocean. It would reduce the stream to the south-east branch and might diminish its volume; but, in view of the form of the South Atlantic depression and its position with reference to the North Atlantic, the warm stream could not fail to continue its flow.

Again, the Arctic region, as F. H. Bradley has suggested, may formerly have had its climate moderated by receiving the Pacific tropical current, through a submergence about Behrings Straits — now only 150 feet deep; and if so, this current, upon the opening of the deep passage for discharge northward, would have been augmented in its size and its heating influence.

Changes in the distribution of climate have been attributed to assumed changes in the position of the earth's axis of rotation. But mathematical investigations by Sir Wm. Thomson, Professor Haughton, Mr. George H. Darwin and others, have shown the hypothesis to be of no geological value. Mr. Darwin has demonstrated that a displacement of the pole of merely 1° 46′ would require that a twentieth of the whole earth's surface should be elevated to a height of 10,000 feet, with a corresponding subsidence in another quadrant; and for one of 3° 17′, that double the surface should have undergone these great changes. Sir Wm. Thomson concludes from his discussion of the subject that "there is no evidence in geological climate throughout those parts of the world which geological investigation has reached to give any indication of the poles having been anywhere but where they are at any period of geological time."

1. SOURCES OF HEAT.

The Earth has three prominent sources of heat: (1) The Sun; (2) The heat of the Earth's interior; (3) Chemical and mechanical action.

1. The Sun. — The heat received by the earth from the sun varies: —

1. *With the Seasons.* — The earth, owing to the obliquity between its equatorial plane (at right angles to the axis of rotation) and the plane of the ecliptic (or that of its orbit) gives more light and heat for about six months to the northern hemisphere than to the southern, making thereby a northern summer with a southern winter; and the reverse for the other six months.

Further, the time of the equinoxes, or that of crossing the equator, northward and southward, is slowly changing backward in the series of months, and in less than six centuries the vernal equinox, now on March 23d, will be in the month of February; thus the summer months after a while will become those of the winter. The rate of the *precession* of the equinoxes is about 50·1 seconds a year, or a degree in about 71·6 years, which corresponds nearly to a month in 2,158 years and a complete revolution in 25,868 years.

2. *With the Time of the Perihelion and Aphelion.* — The sun is now in aphelion during the northern summer and southern winter. With aphelion in winter, the winters are colder and the summers are warmer than with perihelion in winter. The position of the major axis of the earth's orbit (the extremities of which are the aphelion and perihelion points) is changing, and a complete revolution takes 110,000 years; and since this change is in the opposite direction from that of the precession of the equinoxes, above stated, the *cycle of the seasons* is shortened from 25,868 years to about 21,000 years; for supposing the perihelion and either equinox to coincide, and then the precession to move in its direction and the perihelion in the opposite, at their respective rates, they would again be in conjunction, in consequence of these rates, in 21,000 years. Hence, every 10,500 years, the seasons become reversed, that is, the months of our winter become the summer months. Another consequence of this aphelion cycle is, that the winter and summer intervals between the equinoxes vary in relative lengths, the aphelion side being the longer. At the present time the aphelion comes in summer, and the summer-half of the year is eight days longer than the winter.

3. *With Changes in the Eccentricity of the Earth's Orbit.* — The earth's elliptical orbit varies slowly in eccentricity, — that is, in the length of its major axis, — making the aphelion distance greater and

the perihelion less, but not varying the mean distance or the amount of heat received annually by the earth from the sun. Maxima in the eccentricity occur once in 100,000 to 200,000 years. With the sun's mean distance 92,400,000 miles, the present aphelion distance is about 93,950,000 miles, and the perihelion, 90,850,000 miles, the eccentricity being 0·0168. But at a time of extreme maximum eccentricity (= 0·075, nearly) the aphelion distance would be about 99,300,000 miles, and the perihelion 85,500,000, making the sun 13½ millions of miles nearer the earth in summer than in winter.

The eccentricity passed one of its maxima, according to Stockwell's calculations (Am. J. Sci., II., xlvi., 1868), about 110,000 years since (E = 0·0460); another, higher, 210,000 years (0·0575); another, not so high, 300,000 years (0·0424); a rather low minimum, 410,000 years (0·0170); a low maximum, 475,000 years; a very low minimum, 520,000 years (0·0166); a maximum, 570,000 years (0·417); two maxima, the second 750,000 years (0·0575); a very low minimum, 800,000 years (0·0132); an *extreme* maximum, 850,000 years (0·0747); another very low minimum, 900,000 years (0·0102); a maximum, 950,000 years (0·0517); and so on. For the past 50,000 years the eccentricity has been between 0·0109 and 0·0188, and, in 1850, was 0·0168. In future time, there will be a very low minimum, 24,000 years on; a low maximum, 150,000 years; another low maximum, 250,000 years; a very low minimum, 300,000 years; a low maximum, 400,000 years; a very high maximum, 515,000 years.

At the maximum which occurred 110,000 years since, the aphelion and perihelion distances were 96,650,000 and 88,150,000, the difference, 8,500,000 miles. Owing to the increasing eccentricity there is an increasing difference in the length of the winter half of the year as compared with the summer half; and at the extreme maximum, it is 36 days longer than the summer half.

As the amount of heat which the earth receives varies inversely as the square of the sun's distance, increasing eccentricity diminishes the amount on the aphelion side and increases it on the other; and if aphelion comes in winter, the winter cold is greatly augmented, besides continuing longer. The summers, on the contrary, would be proportionally hotter, but, in the same proportion, shorter. With aphelion in summer the winters would be relatively mild and the summers cool. Mr. James Croll, from whom the above on the effects of change in eccentricity is cited, holds that the cold which would be a consequence of the aphelion coming in winter during a period of maximum eccentricity would be sufficient to bring on a Glacial era. He argues that in the north hemisphere, under the supposed condition, "the southeast trade winds would be stronger than the northeast and would blow over upon the northern hemisphere as far probably as the Tropic of Cancer;" so that "all the great equatorial waters of the ocean would be impelled into the northern hemisphere, which would in consequence have its temperature raised, and snow and ice would to a great extent disappear from the Arctic regions." When the earth, on the contrary,

was in aphelion in the northern winter, the circumstances would be reversed, and the warm waters would thus be "wholly withdrawn from the northern hemisphere," causing snow and ice to accumulate in the north. Further, since the cycle of the seasons is 21,000 years, and therefore short compared with a time of maximum eccentricity, there may be two glacial eras in one maximum with an era of unusual warmth in the interval between; and, besides, the glacial era of the southern hemisphere would occur 10,500 years after the northern, that is, when aphelion came in the southern winter.

While it is certain that a period of maximum eccentricity would be favorable for glacial conditions, it is not admitted by all physicists that facts sustain the conclusion respecting the winds and oceanic currents set forth by Mr. Croll, or make the cold sufficient for so extreme results.

4. *With the Changes from Maximum to Minimum in the Spots on the Sun's Surface.* — These changes have a cycle of about 11 years, the minimum occurring on the year 1 of the century, and the year 1878 being therefore at the minimum. How far this cycle is a cycle of changing temperature to the earth is not ascertained.

5. *Owing to a progressing Dimunition in the Sun's Heat, or to Changes in the condition of the Sun's Surface.* — As the Sun, like other heated spheres, has been losing heat by radiation through all time, and probably without any corresponding supply, the earth must receive less heat now than in Archæan time; and its greater heat during the early geological ages may be a chief cause of the warmer climate then over the globe.

6. *Owing to Changes in the Density of the Earth's Atmosphere.* — The atmosphere absorbs and retains heat, and the amount absorbed increases with its density. In early geological time the earth had a denser atmosphere than now, through the presence of more carbonic acid and more moisture, and hence it would have absorbed more of the sun's rays as they passed through it.

For a like reason, the earth's lower plains are warmer than its elevated regions, the atmosphere being rarer above. The lowest places should thus have the warmest climate; and accordingly the basin of the Dead Sea, 1,308 feet below the sea-level, has the heat of the torrid zone.

2. Internal Heat. — A. The *proofs of the existence of a source of heat within the earth*, usually appealed to, are the following: —

(1.) The spheroidal form of the earth (p. 9).

(2.) Borings for Artesian wells and shafts in mines have afforded a means of taking the temperature of the earth at different depths. It has thus been found that, after passing the limit of surface-action, the

heat increases. The average rate is 1° F. for 60 feet of descent. At the Artesian well of Grenelle, a temperature of 85° F. was obtained at 2,000 feet, equivalent to 1° F. for every 60 feet. In Westphalia, at Neusalzwerk, in a well 2,200 feet deep, the temperature at the bottom was 91° F., or 1° F. for 50 feet of descent. At Pregny, near Geneva, a depth of 680 feet gave 63° F. At Yakutsk, Siberia, Magnus found a gain of 15° F. in descending 407 feet, equal to 1° F. for 27 feet. In Algiers, an increase of 1° in 42 feet has been observed; and in the Sahara 1° in 32 feet.

From the average, 1 foot in 60 feet, it follows that the flow of heat from the earth's interior is sufficient "to raise the temperature of the earth by about one sixtieth of a degree Fahrenheit per foot on descending."

The rate 1° F. for 60 feet of descent, in the latitude of New York, would give heat enough to boil water at a depth of about 9,000 feet; and 3,000° F., at a depth of about 33 miles. But the ratio is not an arithmetical one, because both of the greater conductivity of the earth below (owing to greater density) and the increased pressure, and hence the depth of fusion, supposing fusion a fact, much exceeds this amount; but how much, has not yet been determined.

Doubts with regard to the observations on the increase of heat downward in borings, and in shafts in mines, come from the facts that chemical action, as stated beyond; and, prominently, the oxydation of pyrite and other sulphides is a source of heat; and this has always to be considered in such investigations. Besides, local sources of subterranean heat may exist. At the Comstock lode, in Nevada, the temperature of the mine in some parts, at a depth of 1,800 to 2,000 feet, is 130° to 157° F., and over thirty tons of ice per day are expended in keeping the air cool enough for the endurance of the miners. The heat here is probably of subterranean origin, as the region is one of former igneous eruptions.

(3.) The wide distribution of volcanoes over the globe affords evidence of internal heat. Volcanoes, extinct or active, border the Pacific, from Fuegia to Alaska; through the Aleutian Archipelago to Asia; down the Asiatic coast, through Kamtchatka, Japan, and the Philippines, to New Guinea, New Hebrides, and New Zealand; and they constitute half of the islands of this ocean, and two of them, in Hawaii, are nearly 14,000 feet high. This volcanic region is equal to a whole hemisphere, and is therefore evidence of a wide distribution of interior heat. Volcanoes occur also through Java and Sumatra; in central Asia, in the Thian-Shan Mountains; about the Mediterranean and Red Seas; in western Asia, and southern, central, and southwestern Europe; in Iceland, and in the West Indies.

The ejection of melted rock through fissures has taken place over all the continents: in Nova Scotia, Canada, New England, New Jersey, and the States south, the region of Lake Superior, the Rocky

Mountains, and western America; in Ireland, Scotland, and various parts of Europe; and so over much of the globe.

Such facts strongly favor the view that igneous eruptions must for the most part have come either from liquid rock beneath the crust, or from great fire-seas, within it, which originated from the earth's liquid interior. This point is further discussed on page 822.

B. The heat of the Earth's interior has reached toward or to the surface for geological work in three ways.

(*a.*) *By Conduction outward attending the Earth's cooling.* — The amount thus received at the surface may have been sufficient to have modified somewhat the temperature of the oceans, and the earth's climates, during early geological time. At present it is inappreciable; and yet, according to Thomson, the amount of heat now lost by the earth, as a consequence of cooling, is such as would melt annually a complete covering of ice, ·0085 millimeter thick, to water at 32° F., or bring 777 cubic miles of ice to the same state.

(*b.*) *By fractures of the crust, and the escape of melted rock or hot vapors.*

(*c.*) *By an Accumulation over large Regions of a great thickness of Sedimentary Deposits.* — It follows from the conditions of a globe having an internal source of heat, that equal temperatures will exist, as a general thing, at equal depths; in other words, that isothermal planes, or more precisely, *isogeothermal*, will be parallel to the surface; and that they will even bend upward to correspond with the general curve of the broader mountain regions, and downward beneath the oceanic depressions. Consequently, the isogeothermal planes will rise a thousand feet for every thousand feet in depth of deposits spread out over a wide area; and, as urged by Babbage, solidification, crystallization, and other chemical changes may thus be occasioned in the inferior beds, provided the accumulation reaches a depth adequate to raise upward the requisite amount of heat.

Again, the removal of rock-material from wide areas, as is done in the slow processes of erosion, will tend to produce an equivalent depression of the isogeothermal planes.

With reference to a covering of ice over a large region of the globe in a Glacial era, Mr. O. Fisher has deduced by calculation, allowing for the difference in the conductivity of ordinary rock and ice (·00581 and ·00218), and for the lowering of the melting point 0·0137° F. for each additional atmosphere of pressure, and taking one sixtieth of a degree Fahrenheit as the average increase for a foot of descent in the earth's strata, that, *if the mean temperature of the ice at surface were* 0° F., the ice would have for its limit of thickness at which its lower surface would begin to melt, 714 feet. Further, the heat used in the melting diminishes thus much the amount that would otherwise be conducted through into space; but *all* will be used up in the melting after the ice has attained a thickness of sixteen miles. The above *if* is one suggested by Croll with reference to a polar ice-cap; it could not be a fact in any Glacial era for zones outside of

the polar circles, and only for a part of the surface within them. (Phil. Mag., V., vii., 381, 1879.)

3. Chemical and Mechanical Action. — Heat is evolved by chemical changes in which there is condensation, as in liquids becoming solids, or gases, liquids, and in oxydation, etc.; often an effect of the natural decomposition of minerals, or of vegetable or animal matter. The oxydation of sulphides, and especially of the most common of them, pyrite and pyrrhotite, is a source of heat in many mines, and for many warm springs. In the formation of a pound of water from vapor, heat enough is given out, says Tyndall, to melt five pounds of cast iron.

Mechanical action, as the beating of waves on a coast, the falling of water in cascades or rain, the shakings of earthquakes, sliding of rocks, motion of the atmosphere in winds, produces heat, whenever the action meets with resistance, on the principle that motion corresponds to an amount of heat, or that heat is transformed motion. The heat thus resulting is, however, of little geological importance. But the friction attending uplifting, plicating, shoving along fractures, and crushing of rocks, has often been an efficient and wide-reaching source of heat and of geological work, producing among the earth's strata consolidation, metamorphism, and probably even fusion. Mallet concludes, from his calculations, that 7,200 cubic miles of crushed rock would cause heat enough to make all the volcanic mountains of the globe; and that, since the ejections of volcanoes have been going forward through a very long period, the action would require but an infinitesimal amount of annual crushing — not over 0·606 of a cubic mile.

Mallet demonstrates (Trans. Roy. Soc., 1872), by many careful experiments, that the crushing of a cubic foot of syenyte or granite produces 119 to 213¼ degrees Fahrenheit; of two slates, 132·85 and 144·29 degrees; of three sandstones, 32·84, 47·79, 86·13 degrees; of two compact limestones, 20·98, 26·28 degrees; of Devonshire marble, 114·68 degrees. He obtained, for the specific heats of the same rocks, the syenytes and granites, 0·181 to 0·196; slates, 0·201, 0·218; sandstones, 0·233, 0·238, 0·215; common limestone (being mostly in the state of aragonite, as shown by Sorby), 0·245, 0·265; marble (or limestone in the state of calcite), 0·203. He concludes, that each cubic mile of rock of the crust, taking it at the mean density, when crushed to powder develops sufficient heat to melt 0·876 cubic miles of ice into water at 32° F., or to raise 7·600 cubic miles of water from 42° to 212° F., or, taking the average melting point of the rocks at 2,000° F., to melt nearly 3½ cubic miles of such rock if of the same specific heat. Also that, taking the amount of volcanic energy annually expended by our globe as *less than one fourth* of the total telluric heat annually dissipated, this amount is represented by the transformation into heat of the work of crushing about 247 cubic miles of (mean) rock, which is not 1–260,000,000th of the volume of the crust, supposing the crust a fourth of the total volume of the entire globe.

The facts prove that movements causing friction in the earth's rocks have been an important source of heat and of geological change. But it is not certain that there has been the crushing needed to make heat

enough to sustain volcanic action. In Eastern North America at epochs when there was the greatest amount of friction and crushing, — those of the making of the Green Mountains, and the Appalachians,—no volcanoes were made and very little took place in the way of eruptions through fissures ; while at an epoch in Mesozoic time, when little friction and no crushing occurred, judging from the slight change of position in the rocks, extensive doleritic eruptions occurred at intervals for 1,000 miles along the Atlantic border. (See p. 417.) The facts from the region between the summit of the Rocky Mountains and the Pacific are of similar import. Igneous rocks have a close resemblance to granite, dioryte, granulyte and other crystalline kinds, and hence may have proceeded from the fusion of older kinds. But these older kinds derived their material from an older source, and originally from the fused material of the globe ; so that the proof of such an origin by refusion is not established beyond a doubt.

2. DILATATION AND CONTRACTION.

1. *Amount of Dilatation.* — The amount of dilatation of rocks is mostly between 1 and 10 millionths for 1° F.; and one millionth corresponds to 1·67 thousandths of an inch for 100 feet.

Colonel Totten, having observed that the stones of the coping of a wall became loosened from some cause, made experiments, in 1830 to 1833, on effects of change of temperature. He found that an inch of fine-grained granite expands for 1° F. ·000004825; of the granular limestone of Sing Sing, N. Y., ·000005668 ; of red sandstone, from Portland, Conn., ·000009632. See also Adie's results in Trans. R. Soc., Edinburgh, xiii., and Q. J. G. Soc., 1847. Pfaff found for the dilatation between the ordinary temperature and red heat (about 1750° F.) of granite from the Fichtelgebirge, 0·0168; for porphyry from the Tyrol, 0·0127; and for basalt, of Auvergne, 0·0120.

Bunker Hill Monument, a hollow obelisk, two hundred and twenty-one feet high and thirty feet square at base (made of granite blocks), swings to one side and the other, with the progress of the sun during a sunny day — a pendulum suspended from the centre of the top describing an irregular ellipse nearly half an inch in its greatest diameter (Horsford).

2. *The Heat from an External Source.* —The sun is producing somewhere, at all times, alternations of temperature, and thereby change of size and position ; and the same effect comes from changes of temperature, whatever the source. The cause is universal in its action. Such a cause, working day after day about rocky peaks and precipices, causing each day some displacement, may end in degradations of geological importance. Besides shifting the positions of masses of rock, it causes expansion and contraction of thin portions of the exterior of rocks, and in some kinds leads to a peeling off of thin layers, as observed by Shaler, or to the opening of delicate fractures that give access to air and moisture for chemical work.

On some of the Thimble Islands, off the shores of Stoney Creek, Conn., the walls of granitoid gneiss facing the water, are peeling off in laminæ, a third to a half inch thick, without any apparent decomposition, or even a dimming of the lustre of the feldspar or mica; and it may be owing to the heat of the day's sun, and the chilling by the waters when the tide is in. Over the rocky surface of countries within the glacial latitudes of the Glacial period, the scratches left by the glacier are generally, when first uncovered, as fresh as when they were made. But, if the surface be open to the sun's heat and light, and the rains and frosts, for a score of years, far the larger part of the markings disappear; and alternate heating and cooling is an important means of this obliteration.

The sun's heat also produces cracks by drying, as in the case of mud-cracks (p. 84). Such cracks in rocks are recognized by their being very shallow.

3. *The Heat from a Subterranean Source.* — From Totten's experiments as data, Lyell has calculated that a mass of sandstone, a mile thick, raised in temperature 200° F., would have its upper surface elevated 10 feet; and that a portion of the earth's crust, fifty miles thick, raised 600° F. to 800° F., might produce an elevation of 1,000 to 1,500 feet. Cooling again, would reverse the result.

Contraction from cooling in case of fusion, generally produces fractures at right angles to the cooling surfaces; and in this way, "basaltic" columns have been produced (pp. 87, 112). The columns are sometimes curved, when the cooling surfaces are not parallel. In contact with the adjoining rock, the cooled mass is often much fractured in an irregular way, and finer in grain than elsewhere, in consequence of rapid cooling. *Basic* rocks are oftener columnar than *acidic;* injected into *hot* rocks, neither may be so. Sandstones and shales also become columnar, when subjected to a heating and drying.

In a cooling layer of fused rock, the smallest number of fractures that can be opened about a point on its surface by equable contraction is three, and hence this number is the easiest to make; and since three such lines symmetrically placed make angles with one another of 120° (Fig. 1109), the hexagonal prism, more or less regular, is the most common form of the "basaltic" column. In the case of large dikes between walls of rock, that set of divisional planes which is nearly or quite vertical is generally more strongly developed than the others, and this occasions a laminated structure in that direction looking like upturned bedding. Contraction also occasions fractures *across* the columns. After the defining of the columns, the divisional planes between the columns may be to a slight degree cooling surfaces, and the transverse fracture planes are thus sometimes made concave, as explained by Mallet, giving the columns a concave top, as at the Giant's Causeway Dikes sometimes have, from the same cause, fissures of great length and depth parallel to the walls, which are finally filled and become mineral veins.

Fig. 1109.

4. *Expansion and Contraction attending Solidification and Fusion.* — Experiments on the contraction attending solidification of rock material have been made by Bischof, St. Claire Deville, Delesse, and Mallet; and the results of the three investigators last mentioned nearly agree. In solidification, the *glass* state is a consequence of

rapid cooling, and the *stone* state, of slow; and, consequently, glass will become stone, if melted and very slowly cooled.

In passing from the liquid to the glass state, in the case of plate glass, at the Thames Glass Works, the cubic contraction was 1·59 per cent., — 100 parts, by weight, becoming 98·41 (Mallet). In passing from the stone to the glass state, according to Delesse, granite decreases in density 9 to 11 per cent.; syenyte, 8 to 9; dioryte, 6 to 8; doleryte, 5 to 7; trachyte, 3 to 5 per cent. Cast iron loses in density on heating, and also on solidifying; trials gave a density of 7·214 when cold, 6·535 before fusion, and 6·883 when liquid (Hannay). So with lava; its hot crust floats. (See page 810.)

The following are the titles of works and memoirs referred to in the preceding pages in addition to those already mentioned: —

C. BABBAGE: Observations on the Temple of Serapis, 8vo, 1847, Proc. Geol. Soc., ii. 73 (having been read before the Society in 1834), announces the view of an upward rise in isogeothermal planes as a consequence of the accumulation of sediments, which principle was also independently brought forward by Scrope, in his work on Volcanoes.

R. MALLET: On Volcanic Energy, Phil. Trans., clxiii., 1873; clxv., and Proc. Roy. Soc., xxii. 328, 1872; Phil. Mag., IV. xlviii., 41, 1874, and l., 122, 201, 1875. Also Introduction to Palmieri on the Eruption of Vesuvius in 1872, published in 1873. (Amer. J. Sci., III. v., 219, 1873; vii., 145, viii., 140, 1874; x., 256, 1875; a Review by E. W. Hilgard, ibid., vii., 535.)

DELESSE: Bull. Soc. Geol. de France, II. iv., 1380, 1847.

J. G. TOTTEN, U. S. Engineers: Experiments on the Expansion and Contraction of Building Stones, by variations of temperature. Am. J. Sci., xxii., 136, 1832.

3. IGNEOUS ACTION AND RESULTS.

1. VOLCANOES.

The facts relating to volcanoes are here presented under the following heads: (1) General nature of volcanoes, and their geographical distribution; (2) Kinds of volcanic cones; (3) Volcanic action; (4) Non-volcanic igneous eruptions; (5) Heat of lavas, and conditions of volcanic action; (6) Thermal waters, geysers.

1. General Nature of Volcanoes, and their Geographical Distribution.

1. Volcanoes. — Volcanoes are mountains or hills, of a more or less conical shape, in a state of igneous action, and consequently emitting *vapors* and, occasionally, melted rock, or *lava*, with showers of fragments, or *cinders*, from a central opening, called the *crater*. They are conduits of fire, opening outward from within or beneath the earth's crust. An *extinct* volcano is a volcanic mountain that has ceased to be active, — the body, with the fire out.

The lavas flow out either over the edge, or lip, of the crater, or, more commonly, through fissures in the sides, or about the base of

the mountain. The cinders are thrown upward from the vent, or crater, to a great height, as a jet of sparks or fiery masses, and fall around in cooled particles or fragments, which are simply granulated lava: they may build up a conical elevation around the vent, or be carried to a distance by the winds.

When rain or moisture from any source descends with the cinders, the mass forms *tufa*, — a kind of volcanic sandstone or conglomerate, being stratified, granular in texture, not very firm, and usually of a gray, yellowish-gray, yellowish-brown, or brownish color.

2. Geographical Distribution. — Volcanoes occur (1) over the border-regions of the continents, — that is, the regions between the oceans and the summit of the border-range of mountains, as between the Pacific and the eastern limit of the summits of the Rocky Mountains; (2) in the continental islands, or those near sea-coasts; (3) in oceanic islands, nearly all of which, excepting a few of very large size and the coral islands, are throughout volcanic, — and the coral islands have probably a volcanic basis. (4) Volcanoes are most numerous along the borders of the larger ocean, the Pacific, — the mainland, or the islands near by, abounding in them on the east, north, and west, and, to some extent, on the south in the Antarctic seas. (5) They are numerous also in the seas separating the northern from the southern continents, namely, the West Indies, between North and South America; the Mediterranean, between Europe and Africa; the Red Sea, between Asia and Africa; the East Indies, between Asia and Australia, — the whole together making a transverse volcanic belt around the globe. Few exist about the Atlantic, excepting those of the islands. Over the interior of continents, remote from the regions mentioned, they are almost unknown; the Thian Shan region in Central Asia is one of the very few.

(6.) Volcanoes are very commonly in linear series or groups.

1. *Borders of the Pacific.* — About the Pacific, volcanoes occur in Fuegia, the southern extremity of the Andes; in Patagonia; thirty-two in Chili, — that of Aconcagua, 23,000 feet high; seven or eight in Bolivia and southern Peru. — Arequipa, 18,877 feet; nineteen or twenty about Quito, nearly all over 14,000 feet, and among them Cotopaxi, 19,660 feet in altitude (by barometer, Dr. Reiss, in 1873); in Central America, thirty-nine; in Mexico, seven of large size, with others smaller; in California, Oregon, and northwest America, twelve, making a lofty series of snowy summits, 11,000 to 14,000 feet high, — St. Helen's, in Oregon, probably 12,600 feet; Mount Hood, 11,225; Mount Shasta, 14,440. In the Aleutian Islands, which form a curve like a festoon, across the Northern Pacific, there are twenty-one islands with volcanoes; in Kamtchatka, fifteen to twenty; in the Kuriles, thirteen; in the Japan group, twenty-four, some 10,000 feet high; in the Philippines, fifteen to twenty; several along the north coast of New Guinea; a number in New Zealand; in the Antartic, on the parallel of 76° 5′, and near the meridian of 168° E., Mounts Erebus and Terror, 12,400 and 10,900 feet high, both in full action when seen by Ross, in 1841; and, more to the east, south of Cape Horn, Deception Island and Bridgman's.

2. *Over the Pacific.* — At the Hawaian Islands, there are remains of ten or more volcanic mountains; and two on Hawaii are now active, — Mount Loa, 13,760 feet high, and Mount Hualalai, about 10,000 feet; while Mount Kea, on the same island, 13,950 feet high, has not been very long extinct.

There are other volcanic mountains at the Society group, Marquesas, Navigator, Friendly Islands, Feejees, Santa Cruz group, New Hebrides, Ladrones; among which, Tauna and Ambrym in the New Hebrides, Tafoa and Amargura in the Friendly group, Tinakoro in the Santa Cruz group, and two or three in the Ladrones, are in action.

3. *Over the seas that divide the northern and southern continents from one another, and the regions in their vicinity.* — (*a.*) The West Indies, where ten islands are eminently volcanic. (*b.*) The Mediterranean and its borders, as in Sicily and the islands north; Vesuvius, and other parts of Italy; Spain, Central France, Germany etc., in Europe; the Grecian Archipelago, which contains five volcanic islands, — Santorin, Milo, Cimolos, Polenos, and Minyros; in Asia Minor, where are the Catacecaumene and other volcanic regions; and, more to the eastward, toward the Caspian, Mount Ararat, 16,950 feet high; Little Ararat, 12,800 feet; Demavend, on the south shore of the Caspian, 20,000 feet. (*c.*) The Red Sea, along its southern borders, where there are a number of lofty volcanic summits. (*d.*) The East Indies, where there are two hundred or more volcanoes, of which there are nearly fifty in Java alone, according to Dr. Junghuhn, and twenty-eight out of the fifty now active; nearly as many in Sumatra; one hundred and nine in the small islands near Borneo; a number in the Philippines, etc.

4. *In the Indian Ocean.* — A few in Madagascar; also the Isle of Bourbon, Mauritius, and the Comoro Islands, and, to the south, Kerguelen Land, etc.

5. *On the Atlantic Borders.* — Only in the Bight of Benin, on the African coast, where one in the Cameroons Mountains is said to be 14,000 feet high; and the neighboring islands, from Fernando Po to Annabon.

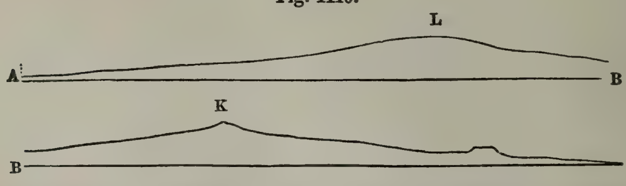
6. *In the Atlantic Ocean.* — St. Helena, the Cape Verdes, Canaries, Madeira, Azores, and Iceland. All the islands of the deep part of the ocean (that is, not on the European or American borders) are volcanic.

7. *Over the Interior of the Continents.* — In America, North and South, there are none east of the Rocky Mountains and Andes; in North America, there are extinct cones at the summit of the Rocky Mountain chain, about the head-waters of the Yellowstone, but none east of its crest range. In Africa, none are known. In Asia, there is a small volcanic region in the Thian-Shan Mountains, at Pe-schan and Turfan, besides hot springs near Alak-tu-kul, and some other spots in that vicinity. In Australia, none are known over the interior, the few observed being situated near its southern border.

2. Kinds of Volcanic Cones.

As the volcanic mountain is made from its own ejections, it may consist either (1) of *lava alone;* (2) of *tufa alone;* (3) of *cinders*

Fig. 1110.

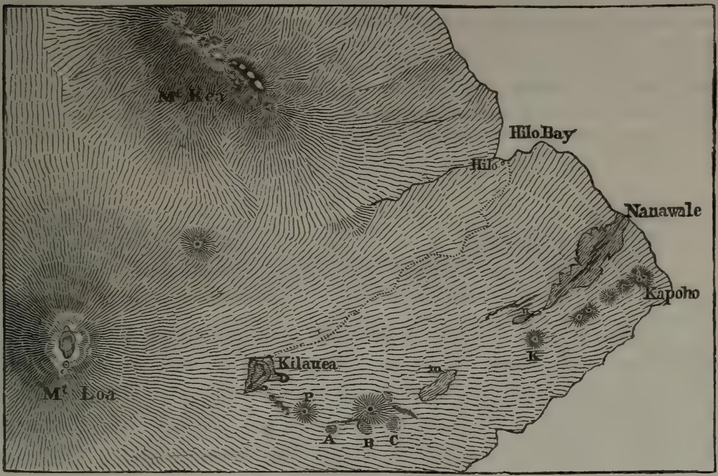


A, B, B, C, profile of Hawaii, as seen from the eastward; L, Mount Loa; K, Mount Kea.

alone; (4) of *combinations of lavas with either cinders or tufas, or with both.* The last is the more common kind.

1. *Lava-cones.* — Lavas, when quite liquid, flow off naturally at a small angle — usually between three and eight degrees. The great volcanoes of Hawaii, Mount Loa and Mount Kea, shown in the map (Fig. 1111), and sections of which are given in Figure 1110, are

Fig. 1111.



Map of part of Hawaii.

mainly lava-cones; and the general slope is six to eight degrees. Ætna has a similar low inclination. A horizontal section of Mount Loa, 1,800 feet below its top, would be nearly twenty miles broad.

In true lava-cones, like Mount Loa, the *crater* is generally a pit-crater, — a great depressed area in the surface of the mountain, like a

Fig. 1112.

Crater of Kilauea, in 1840: *a*, large boiling lake of lava; at *o* and near *e*, sulphur-banks; *r*, an adjoining small crater; *p*, neck between Kilauea and the crater *r*.

pit or quarry-hole in a plain, as in the summit-crater of Mount Loa and in Kilauea, the latter 4,000 feet above the sea. A larger bird's-eye

view of Kilauea (with an adjoining small crater, *r*) is shown in Fig. 1112, and a vertical transverse section of the same, more enlarged, in Fig. 1113. The pits have precipitous walls of stratified rocks; for the lavas are in layers, and the layers are nearly horizontnl.

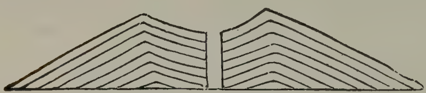
At Mount Loa, the summit-crater is 13,000 feet in its longer diameter, and 780 feet deep. Kilauea is 16,000 feet in its greatest length, seven and one half miles in circuit, nearly four square miles in area, and 600 feet deep. After its last great eruption, of 1840, the pit at centre (Fig. 1113, *p p*) was 1,000 feet deep, with a ledge around — the "black ledge" — (*no n′o′*) 600 feet down. The crater is as much open to the day as a city of two miles square would be, within an encircling wall of six hundred feet (the present depth); and the pools of boiling lavas and vapors (one of which is at *a*, Fig. 1112) may be as leisurely surveyed from the brink as if the objects were gardens and cathedrals.

Fig. 1113.

Vertical section of crater of Kilauea, 1840.

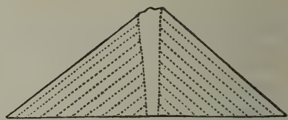
2. *Tufa-cones.* — Flowing mud from a boiling basin, or cinders wet with water and steam, will take a larger angle of flow than lavas; and tufa-cones, therefore, have commonly an angle of between fifteen and thirty degrees. The layers usually slope inward toward the bottom of the crater (Fig. 1114), as well as outward down the sides.

Fig. 1114.



Section of a tufa-cone.

Fig. 1115.



Assumption Island, one of the Ladrones.

The tufa has a brownish-yellow color, owing to the action of the steam or hot water on the cinders, oxydizing part of the iron in the minerals (pyroxene mainly) of the lavas, and making a hydrous sesquioxyd. The *crater* is generally saucer-shaped. Such cones are among the results of lateral eruptions about great volcanoes near the sea.

3. *Cinder-cones.*—Falling cinders may make a declivity of about forty degrees. The eruption of cinders, therefore produces a *crater* with a narrow throat, a narrow rim above, steep sides, the slope thirty-five to forty degrees (Fig. 1115). If the volcano is in brisk action, the space within the crater is dark with the rising vapors; and the explosions attending the ejection of cinders occur usually at short intervals.

The cone is at first nearly black or brownish-black; but, if not soon covered with vegetation, it often becomes, through atmospheric agencies, of a red color, from the oxydation of the iron in the lava: the sesquioxyd of iron formed differs from that of the tufa-cone in not containing water, and hence the difference of color.

4. *Mixed Cones.* — The cones which, like Vesuvius, and many of the great volcanic peaks of western America, as Cotopaxi, Arequipa, etc., are formed partly of lava and partly of cinders or tufa, may have any angle of slope, up to thirty-five degrees. They may be lava below, and terminate in a lofty cinder-cone of forty degrees. The *crater* may be nearly like that of the cinder-cone, — a deep cavity, with the walls thin, compared with those of the simple lava-cone. There is no fixed order in the alternations of lavas and cinder or tufa layers; the lavas have generally flowed out most freely in the early stages of a volcano.

3. Volcanic Action.

1. AGENTS CONCERNED.

The agents concerned in volcanoes are (1) lava; (2) vapors or gases.

1. *Kinds of Lava and Volcanic Rocks.* — The cooled lava of the volcano is usually more or less cellular, because of the expanding vapors in it while it was hot, though sometimes quite free from cellules. The more cellular kind is called *scoriaceous lava;* or, if very openly cellular, *volcanic scoria*, or *slag.* The *cinders* and *ashes* (*lapilli* of the Italians) are fragments of scoria or lava. A layer of the stony lava, when it has flowed from open vents, like those of Kilauea, has sometimes an upper portion, a few inches thick, of scoria, which was like a scum on the liquid stream, and this scoria is often glassy, like the slag of a furnace.

The kinds of igneous rocks are described on pages 76 to 79. Among these, the most common are: (1) *Trachyte* and *felsyte*, *acidic* rocks, alike in consisting chiefly of orthoclase (potash-feldspar); and (2) *dolveryte* (of which *basalt* is a variety), a heavy *basic* rock, consisting of the iron-bearing mineral augite and the lime-and-soda feldspar labradorite, with some magnetite. The latter often contains chrysolite (olivine), and is then called *peridotyte.* The common Vesuvian lava is a heavy augitic rock like doleryte, but it contains leucite (a potash-yielding mineral, called *amphigene* in France), in place of labradorite, and it is named *amphigenyte.* Of these kinds, doleryte is far the most abundant. The felsyte is often porphyritic, or *porphyry.* Dioryte, andesyte, augite-andesyte, syenyte, granite, are among the less common igneous rocks. Andesyte is very common in western America.

Volcanic glass and pumice (the latter a light feldspathic scoria), occur often with feldspathic lavas. The glass, when microscopically examined in thin slices, is found to contain incipient crystals; some of them in short prisms (*belonites*), supposed to be feldspar, and others capillary (*trichites*), which have been thought to be hornblende; and

it graduates through pitchstone and pearlstone into trachyte — slow cooling making the material stony. Daubrée has converted obsidian into trachyte (by subjecting it in a confined vessel to heat and steam), producing orthoclase in crystals. Augitic lavas are less commonly in the glassy state than the orthoclase lavas.

2. *Volcanic Vapors or Gases.* — The material escaping in the state of vapor or gas is almost wholly (1) the vapor of water. Besides this, there are (2) atmospheric air, and (3) sulphurous acid; and sometimes also (4) carbonic acid gas, derived, probably for the most part, from limestone beds in the vicinity of the vent, and (5) hydrochloric acid, derived mostly from sea-water; also, in the neighborhood of volcanoes, but not ordinarily from the lava-vents, (6) hydrogen, (7) nitrogen, and (8) sulphuretted hydrogen. Flames are never seen rising from the lavas, except through the imagination of the beholder; and the so-called "thick smoke" is vapor of water, with usually a little sulphurous acid, and some atmospheric air. Boussingault detected no hydrochloric acid in the vapors of the South American volcanoes.

Hydrogen was detected by Deville and Le Blanc in fumaroles nearer the lava-vent than those affording the sulphuretted hydrogen, but not in vapors from the melted lavas; they also detected it in vapors from the old lavas of Torre del Greco, and in the Tuscan lagoons; and Bunsen, in the Solfataras of Iceland.

2. VOLCANIC PHENOMENA.

The more common phenomena are, in brief, as follows: —

(1.) Movements resembling sometimes those of a boiling liquid in the lavas of the crater, with the escape of steam, and other vapors; (2) rising and projectile effects caused by the confined vapors; (3) fracturing of the volcanic mountain or the region around; (4) eruptions of lava from the crater or from the fissures opened, sometimes flooding the region with lava streams; (5) making of cinder-cones from the dry cinders falling about a vent; (6) making of tufa-cones and flowing streams of cinders, when water is present to wet the falling cinders, — either the waters of the ocean or of subterranean fresh-water streams, or those of the clouds precipitated in rain during the eruption; (7) underminings of the region by the outflows, leading to subsidences of wide extent. (8) In addition, there are often, in the vicinity of volcanoes, fissures through which steam rises, with sulphur and other vapors, as explained on pp. 736, 737.

Cinders are cooled fragments of lava-bubbles. The bubbles made in the lava of a vent by the escaping vapors, finally burst, and the material thrown up comes down *cinders.*

The further explanations of these phenomena are best appreciated from the facts connected with particular volcanoes; and for this pur-

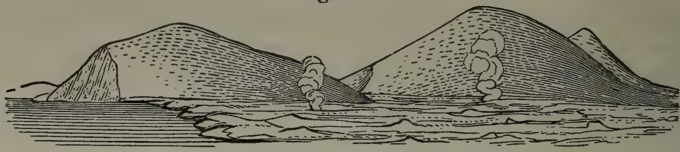
pose the volcanoes of (1) Mount Loa; (2) the Lipari Islands; (3) Vesuvius, and (4) Mt. Shasta, are selected as representatives of the more prominent kinds.

1. *Mount Loa, Hawaii.* — In the summer of 1840, the pit or crater of Kilauéa, after one of its great eruptions, had the depth and form shown in Figs. 1112, 1113. The lava in the great lake (a), 1,000 feet in its longest diameter, was seemingly in ebullition over its whole surface, jets of liquid rock 30 to 60 feet in height, occasionally rising to two or three hundred, being in constant play, with ordinarily no sounds but those resembling the muttering of a great boiling cauldron. Toward the middle of the pit, other smaller pools were in similar action. Vapors rose in a great column from the fiery portion of the pit, and spread out in a broad canopy over the crater. The depressions or pits occupied by the boiling pools were circular, or nearly so, and evidently because this is the form given by free ebullition. At intervals, the great lake overflowed, or lavas welled up through fissures radiating from it, and the streams spread more or less widely over the bottom of the pit — whose area, it is to be remembered, was large enough to allow of a flow more than two miles long. These ejected lavas speedily blackened with cooling, and in a few hours could be traversed safely and without inconvenience. Thus simple and quiet was the action of the great volcano; and the same was its usual habit, — though with variations in activity, the boiling sometimes almost ceasing, sometimes more active and attended by detonations. Through such overflowings at bottom the lower pit was losing its depth. In eight years between 1823 and 1832, and between 1832 and 1840, it was nearly obliterated by its reaching the level of the "black ledge" ($n\ o$, $n'\ o'$, Fig. 1113). With the augmented height in the lavas, there was also augmented intensity in the fires; new boiling lakes opened, and outflows of the lavas became almost incessant, making the wide interior, according to the descriptions given, literally a sea of fire, yet a harmless one to the observer at the brink of the pit.

Having reached this state, the eruption of 1840 took place; and quietly, like the preparation, the first signal to the natives on the coast being, not an earthquake, but a "fire in the woods." As a consequence of the outflow, the lavas sunk 400 feet in the crater, so that there was again a "lower pit" ($n\ p$, $p'\ n'$); it escaped, however, by fissures, not by an overflow from the crater. Six miles to the east a fissure opened and some lavas escaped; in the next seven miles there were other fissures, giving out steam and making small patches of lava. Finally, twelve miles from the sea and twenty-seven from Kilauea, at a height of 1,250 feet above tide level, an outflow began

from fissures, and continued till it reached the sea at Nanawale, where three tufa-cones (Fig. 1116) were thrown up over points in these fissures, made from cinders or volcanic sand, produced by the chilling action of the waters on the escaping lavas.

Fig. 1116.

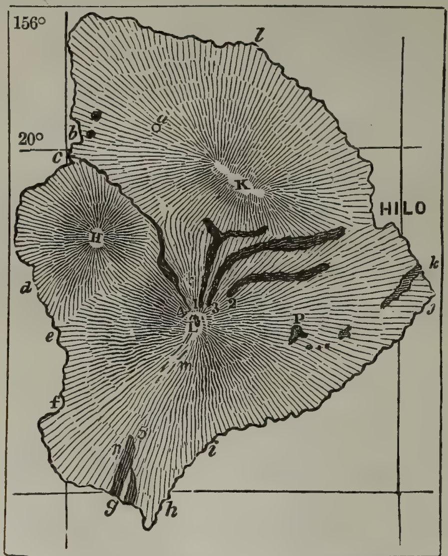


Tufa-hills, Nanawale.

The facts then are these: The bottom of the emptied pit, after the eruption of 1832, was about 3,000 feet above the sea-level. Gradual overflows filled it to 3,400 feet. Then, 2,150 feet below this level, and 1,250 above the sea, the mountain was tapped, and the lavas ran out.

Of similar character has been the action of the summit crater of Mount Loa. The courses of some of its recent lava-flows are given on the following map.

Fig. 1117.



Island of Hawaii. — L, Mount Loa; K, Mount Kea; H, Mount Hualalai; P, Kilauea or Lua-Pélé; 1, Eruption of 1843; 2, of 1852; 3, of 1855; 4, of 1859; *a*, Waimea; *b*, Kawaihae; *c*, Wainanalii; *d*, Kailua; *e*, Kealakekua; *f*, Kaulanamauna; *g*, Kailiki; *h*, Waiohinu; *i*, Honuapo; *j*, Kapoho; *k*, Nanawale; *l*, Waipio; *m*, first appearance of eruption of 1868; *n*, Kahuku. The courses of the currents, 1, 2, 3, and 5, are from a map by T. Coan, and 4, from one by A. F. Judd.

The outflow in January, 1843 (1, Fig. 1117), began in silence, at a height of 13,000 feet above the sea, and spread northward and westward for 25 or 30 miles, finishing its work without an earthquake. Again in February, 1852, a bright light at the very summit was the first announcement of another eruption (2, Fig. 1117). Three days later, the eruption was continued in an outbreak 4,000 feet lower, which was also a quiet one; and at this second opening, as described by T. Coan, a fountain of fiery lavas, 1,000 feet broad, played to a height at times of 700 feet, with indescribable grandeur and brilliancy. There were rumblings and mutterings from the plunging flood, and explosions, but no earthquakes. (Am. J. Sci., II. xiv. 1852, xv. 1853.) In 1855, another eruption (3, Fig. 1117) began without noise or shaking as before, at an elevation of 12,000 feet. The length of the stream of lava was sixty miles. In January, 1859, another eruption (4, Fig. 1117) made its first announcement at the summit in the same quiet manner as the preceding; it, however, ended at a point on the northwest side of the mountain, 1,500 feet above the sea, in a fiery fountain, the lavas being thrown up "like the waters of a Geyser" to a great height.

In each of these summit eruptions, there were *no earthquakes* beyond slight quiverings; and *Kilauea*, although so large a pit, and in full action, *showed no sympathy.*

In 1868, on March 28, another summit eruption commenced; but — unlike the others known — it was attended with violent earthquakes; and besides, Kilauea took part. As late as April 10, four "fountains of lava" were playing near Kahuku (*K*, Fig. 1117) to a height of 500 to 1,000 feet. Kilauea was simultaneously emptied, its bottom sinking, when the Kahuku outburst began, 300 to 400 feet, as at the eruption of 1840, and the bottom of the great lake dropping 400 feet lower, making a pit a mile across its floor (by Mr. Coan's measurement), within the area of the great pit, Kilauea.

During the ten years following this eruption, Kilauea had become again filled by the overflowings of its great lake and fissure outflows, nearly to the level of the Black Ledge; and then the quietest of all its eruptions took place; the lavas ran out without any announcement with not even a steaming fissure to indicate its underground course; the bottom of the lake sank 300 feet. There were some unusual but light waves in the ocean, which, as Mr. Coan states, suggest that there may have been a submarine outflow.

At some of the eruptions of Hawaii the outflows have been beneath the sea-level, as shown by the great number of dead fish thrown up on the coast.

Catastrophic eruptions have occurred in the Hawaiian Islands far exceeding in vio-

lence that of Mount Loa in 1868. The extinct volcano of eastern Maui, 10,217 feet high, which bears abundant marks of recent action, has a crater between 1,000 and 2,000 feet deep, exceeding much that of Kilauea. From two sides of it, the east and north, lava-flooded valleys, *one to two miles wide*, go off toward the sea. They are due to two fractures made at a summit-eruption, in which floods of lava were poured forth and a quarter of the volcanic mountain was started from its foundations. In Oahu, the eastern of its two volcanic mountains retains the regular slopes of its old volcano on the sides facing southwest and south ; but on the north and northeast, a long precipice, fluted and gorged by erosion, is a vertical section of the stratified lavas; and it indicates that a part equal to two thirds of the original volcanic cone was broken off at an eruption and has been lost by subsidence in the depths of the sea.

The rock of all these eruptions is a heavy grayish-black doleryte (or basalt), more or less scoriaceous ; and most of it is chrysolitic. The glassy grains of this mineral make a considerable part of the sands along the sea-shore reached by the eruption of 1840, and are common elsewhere. The rock of fissures is often free from cellules ; and in some places — as near Hilo — there are beds of solid columnar basalt. Part of the basalt is porphyritic. Feldspathic rocks also have been ejected in former time, and even after Mt. Loa had reached its present height; but no recent eruptions of this kind have occurred.

The feldspathic rock of the summit is free from cellules and looks like a somewhat laminated phonolite. According to Dr. C. Pickering, it forms the western wall of the summit crater. A similar compact feldspathic rock constitutes hills in the western part of Oahu, about the central portion of a profoundly eroded volcanic mountain.

The cooled lava of the bottom of Kilauea has a surface crust, four to six inches thick, of glassy scoria, which is the hardened scum or froth; and below this it is solid rock, often containing only a few ragged cellules.

But the lava from fissures outside of the pit is usually free from the scoria ; the surface is hard and compact, but looks ropy, owing to the marks of flowing.

If a stream of lava stops in its course, it begins at once to harden; then, when made to move again, from another accession of lavas, the thick hardened crust breaks up, like ice on a pond, but makes cakes and blocks, 100 to 10,000 cubic feet in size, black and gray and bristled all over with jagged points and angles. On Hawaii, such blocks lie piled together over extensive areas, making what are called there, *clinker-fields ;* and they are regions of the most horrid, chaotic desolation. The streams of hardened lava over the land often rise into great protuberances, many yards across, with oven-shaped cavities within, which were formed by waters beneath that were evaporated by the heat while the flow was in progress.

2. *Lipari Islands.* — The Lipari Islands, north of Sicily, are all volcanic, and vary in height from 1,601 to 3,125 feet. Stromboli, 3,090 feet high, is the northern island, and Lipari (1,601 feet) and Vulcano (1,978 feet) are the southern. The points of most prominent interest are the following : —

(1.) The ejections of later times, unlike those of Hawaii, are chiefly of cinders, and the volcanic mountains are largely cinder cones.

(2.) The last lava ejection of Stromboli took place in 1786 ; since then it has been in constant activity, though with varying intensity. Spallanzani witnessed in 1788, and described well, its mode of action, the sinking of the lava in the throat of the crater for twenty feet or

so; its rising again; then the swelling up of great bubbles over its surface, made by the vapors in their effort to escape; finally, the bursting of the bubbles, and the ejection of the material to a great height, to fall as cooled cinders; and so on, in constant succession at short intervals.

(3.) The ejections of the northern island (Stromboli) are of the heavy *doleritic* or basaltic kind; those of the southern (Lipari and Vulcano), are *trachytes*, or the lighter feldspathic; while in the intermediate Panaria group (a half submerged volcano) they are of intermediate character, called *trachydolerytes* by Abich. But on Stromboli there are older feldspathic kinds at the centre. The trachyte of Lipari is mostly quartz-trachyte (called *Liparite*), a rock having nearly the constitution of granite; and with it occurs volcanic glass, or obsidian, which is sometimes in streams that bear evidence of sluggish, twisting flow. Pumice, a common variety of the scoria, is an article of export from the island. (See further on the Lipari Islands, J. W. Judd, Geol. Mag., 1875.)

3. *Vesuvius.* — Vesuvius is nearly 4,000 feet in height. It is the remains of a large ancient crater, part of the walls of which constitute the ridge on the north, called Somma.

(1.) It is remarkable for large and lofty cinder ejections, and frequent outflowings of lava. The mountain, with the region at its base, consists of lavas, beds of tufa, and cinders, interstratified with one another, but with the tufa most abundant below, and the cinders often forming a high cinder cone at the top of the mountain. The cinder ejections of 1779, according to Sir Wm. Hamilton, were thrown to a height of 10,000 feet. The fact proves (1) the vast projectile force of the bursting bubbles in the crater; and (2) the great viscidity of the lavas.

(2.) In preparing for an eruption the great crater has become, by a more or less gradual process, filled by the lavas; and this has sometimes gone on until the depression at the top, or the crater, had disappeared, and a broad lava plain surmounted by a cinder cone formed the summit. At the same time, the ejections of fiery cinders have increased in frequency from one in five or ten minutes, to an uninterrupted volley of them; and then, the sides of the mountain, on one side or another, have been broken, and the lavas have flowed out, emptying the crater once more and revealing a gulf perhaps one or two thousand feet deep. Thus, with all the irregularities, the action is in a general way similar to that of Hawaii.

(3.) The eruptions have usually been attended by heavy earthquakes, unlike those of Hawaii.

(4.) In its eruptions, the sea has sometimes had access to the fires

through opened fissures, for the hydrochloric acid in the vapors and the chlorids among the saline effloresences indicate a marine source for part of the waters.

Its eruptions have taken place at very irregular invervals, and with increasing frequency in later times. At the commencement of the Christian era it was a vine-clad mountain, apparently a burnt-out volcano. In 79 A. D., after several years of occasional earthquakes in the region, the fires broke out anew, amid heavy shakings. The summit of the mountain was engulfed, leaving Somma to mark the former northern limit. No lavas outflowed, as far as known, but cinder ejections occurred on a vast scale, and the rain from the clouds of vapor, produced, with the fallen cinders, a flowing mud which buried the cities of Pompeii and Herculaneum. The partly hardened mud is tufa. Many eruptions of Vesuvius have occurred since, but, until recently, only at very long intervals. Nearly a thousand years passed before the next recorded eruption, or that of 1036; and a century or more intervened between the most of the outbreaks of the next 600 years. In 1631, both lavas and cinders proved destructive to cities and villages around the mountain; but, for years before, the crater, then five miles in circumference, had been a grazing ground for cattle. Since 1631 the eruptions have been very numerous. Vesuvius is hence an example of a volcano which has *increased in activity* during the past 2,000 years.

Besides ejections of fused material, the volcano has thrown out in former times masses of limestone and other rocks, which were torn from non-volcanic terranes along the throat of the volcano. From these masses come the vesuvianite, humite, mica, and various other species in well-crystallized specimens which are obtained about Somma.

4. *Mount Shasta.* — Mount Shasta, in Northern California, is one of a series of great volcanic mountains on the Pacific border of North America. It is at the southern extremity of the Cascade Range, which is largely of volcanic origin, Mt. Jefferson and Mt. Hood standing in the line south of the Columbia River, and Mt. Adams, Mt. Henry, Mt. Rainer, and Mt. Baker, north of the same, the height of no one less than 10,000 feet. Besides, it makes the northern extremity of the Sierra Nevada — which is continuously volcanic at surface from Mt. Shasta to Lassen's Peak, a cone 10,500 feet high on the northern border of Plumas County, and has extensive cappings of lava far south of this point. Mt. Shasta, according to Whitney, is 14,440 feet high, 10,000 feet of which rise above the crouching hills at its base.

(1.) Like most of the great volcanoes of Western America, South as well as North, it has steep sides, the angle of slope averaging 30°. The view here given is from a photograph by Watkins. (2.) Like the others of the Cascade Range it is a volcano that has had great eruptions in the past; but none within recent times, showing a decline in volcanic activity. It appears to be wholly extinct; but Mt. Hood, of the same range in Oregon, has still some heat and vapors escaping at top. (3.) Its surface lavas are to a large extent basaltic, but trachytic kinds occur toward the base. (Whitney.) (4.) A wide region of basaltic lavas, from fissure eruptions, surrounds it, and each of the other volcanoes of the series. The accumulated beds in the vicin-

ity of Mount Hood, Oregon, cover many hundreds of square miles; and the thickness on the north side of it, where they are cut through by the Columbia River, is, according to Le Conte, not less than 4,000 feet, the range in this part consisting almost solely of successive beds of lavas. The name *Cascade*, applied to the Range, comes from the cascades in the river along this cut. The rocks, as described, are basaltic lavas above, and trachytes and porphyry below.

Fig. 1118.

Mount Shasta From a Photograph by Watkins.

Besides these rocks, there are extensive beds of tufa, interstratified with the lava stream, or making the surface deposits. The winds of the region being mostly from the west the tufa deposits are largest to the eastward of the Cascade summits. Mr. Condon speaks of travelling over such an area, for 50 to 60 miles, and states that the volcanic ash was evenly laid over the whole surface, like a covering of snow; and where attaining its greatest thickness, the sharp features of the older surface ceased to show themselves through it. In many parts of the Rocky Mountain regions, the tufas contain silicified stumps and trunks of large trees (p. 709). On the north face of Amethyst Mountain, in the Upper Yellowstone region, where the volcanic tertiary beds are 5,000 feet thick, upright trunks occur at many levels, some 30 feet high, while prostrate trunks are met with 50 to 60 feet long and 5 to 6 feet in diameter. (Holmes.)

Other Volcanic Phenomena.

(1.) In *submarine eruptions*, islands have been made by the ejections. Such islands may consist of lava below, but are certain to be of scoria, conglomerate, and tufa above through the action of the cold waters on the lava, if not so from cinder ejections. An island named Graham Island, was thus made in a few days in 1831, off the south coast of Sicily. It had a height above its base of 800 feet, 200 of this above the sea-level; but by the close of the year it had disappeared through the wear of the sea, leaving a shoal in its place.

(2.) *Volcanic bombs* are thrown from some craters when the lavas are rather viscid. They have usually a centre of grains or masses of infusible material, which the movement in the lavas has rolled together into a mass; the indigestible cud is ejected with the cinders, and becomes further rounded in the rotation through the air. Such bombs are sometimes twelve or fifteen feet in diameter. At the Eifel, in Prussia, a region of extinct volcanoes, the interior is mainly chrysolite; and at the island of Lipari, it is feldspathic scoria, with some chrysolite.

(3.) A *circulating movement*, like that of a boiling cauldron, has been observed in the lava of Kilauea. In the lava-conduit, the greatest heat is along the centre, most remote from the cold sides. Hence the ascent from inflation by rising vapors would be greatest at the centre, which should determine a flow at surface from the centre to the sides. This was exhibited on a grand scale at Kilauea, in 1840, where the liquid lava in the great lake 1,000 feet across (*a*, Fig. 1112, p. 725), seemed like a river that came to the surface for a moment and then disappeared. The area of greatest heat was near the northeast side of the lake; and the stream seemed to flow to the southwest.

(4.) The *slope of flowing lava*, while generally small and producing cones of small angle, *may be of almost any angle*. It forms continuous streams of 30°; and even vertical cascades of solid lava occur about Mount Loa and other volcanoes. As Prévost observed, flowing lava, like flowing beeswax, if stream follow stream rather rapidly, and not too copiously, so that one becomes melted to another, may make layers of great thickness, having a large angle of inclination. Hence, while the average angle of a lava-cone is small, because lavas when in a very large outflow spread rapidly and easily, there are many regions of much steeper angle, over its declivities. The author observed a stream descending into the crater of Kilauea, at an angle of 30°. It was, however, hollow, the interior having run out after the crust had formed. Mr. Coan mentions the frequent occurrence of slopes of 15° to 20° and more, along the stream formed at the eruption of Mount Loa in 1855. Columns of lava-drops rising from a spreading base, looking like petrified fountains, are formed, when small jets of lava are thrown vertically from a hole, and fall back on one another before cooling. The stony drops are sometimes less than half an inch across, and thus evince the remarkable liquidity of the lavas.

(5.) *Lavas cool at surface suddenly owing to contact with the air*, and make thus a crust a foot to a yard thick; but underneath this crust of poorly conducting material, the further cooling goes on with extreme slowness, varying in rate according to the thickness of the mass. The liquid part below often flows on and leaves open chambers or long passages.

(6.) The *texture* of the rock made by solidification is fine-grained or coarse-grained, contains much glassy material, or little or none, according to the rate of cooling, and some other conditions, especially the not too free supply of moisture within the lava. In the final cooling of the interior of a volcano, the rock is sometimes granite-like in its coarse crystallization owing to the slowness of the cooling process.

(7.) **Solfataras.** — Solfataras are areas where sulphur-vapors escape, and sulphur-incrustations form. They occur away from intense volcanic action, where sulphur vapors and steam rise slowly. Incrustations of alum are common in such places, arising from the action of sulphuric acid on the alumina and alkali of the lavas. The decompo-

sition of the lavas thus occasioned often results in producing gypsum (or sulphate of lime), through the action of the sulphuric acid on the lime of the feldspar or pyroxene; also opal, or quartz, or siliceous earth, from the silica set free; and impure clay. Carbonic acid is sometimes given out in such places, when there is limestone below to be decomposed, — some acid (either sulphuric acid or silica in solution) setting free the carbonic acid, by combining with the lime. The "solfatara," miles north of Naples, is the best known and earliest described of such regions.

Fumaroles are cavities in the lavas of a volcano, or in a solfatara, whence steam issues freely. The steam and acid vapors often produce beds of whitish and red earth through the decomposition of the lavas; incrustations of sulphur about the vents, or beneath an outer firm layer of the earth; druses of crystals of hematite or magnetite in the cavernous lavas, as at Vesuvius, Sicily, Stromboli, derived, it is supposed, from the reaction of steam on vapors of iron chloride; sometimes, at Vesuvius, incrustations of common salt and of sal-ammoniac and various other products.

3. GENERAL CHARACTER OF VOLCANIC ACTION.

The preceding facts lead to the following conclusions: —

(1.) *Quiet Eruptions.* — In large volcanoes, like those of Hawaii, when the lavas are free-flowing, *eruptions may take place without earthquakes*, or violence of any kind; and be the result of *gradually accumulating pressure* (1) from the increasing height of the column of lavas, and (2) from the increasing amount of escaping vapors. The pressure per square inch of 100 feet of the liquid lava (the specific gravity of the rock being 2·90–2·93, but making a deduction of one-tenth for liquidity and the contained vapors) is about 120 pounds; or for 3,000 feet, 3,600 pounds; and for the height of the mountain, 13,760 feet, about 16,500 pounds. The great lava fountain of the summit-eruption of 1852 had a head of lavas above it over 3,000 feet high; and hydrostatic pressure, as Mr. Coan suggested, may in this case have been the chief force at work.

But in general the other agency — that of evolved vapors — has acted along with the pressure of the lavas.

The great efficiency of this cause, even in Kilauea, is apparent from an occurrence at the eruption of that crater in 1840. A fissure was opened to the top of the walls of the pit, 500 feet above the boiling lavas of the interior, and liquid rock flowed from it down the slopes to the black ledge. The vapors must have been the chief cause of such a fracture, and of outflow at a height so far above the level of the crater's boiling lakes. In the case of the fountains of lava near Kahuku, mentioned above, it may be that the jets were produced by the access of waters to the liquid lavas beneath; but they were more probably due to the column of lavas in Mount Loa.

(2.) *Catastrophic Eruptions.* — In other cases, especially when the lavas are quite viscid, as at Vesuvius, where the eruptions are usually attended by earthquakes, they depend perhaps most largely on the access of marine or fresh waters, and the consequent sudden production of vapors; but even in such, there is usually a *gradual* increase in height of the lavas going on through years, preparing for the catastrophe.

(3.) *Projectile Power inversely as the size of the Crater.* — Great craters, like the Hawaiian, have little projectile power because of the liquidity of the lavas; and little ones large, for the reverse reason. Free liquidity leads to great size of the crater, as well as a pit-like form; and viscidity to relatively narrow throats. With the former, cinder ejections are usually few and low and the cones that are made are small; with the latter, large and high, because the vapors are kept from escaping until they have collected into very large bubbles, and the cones are sometimes several thousands of feet high.

(4.) *Periodicity in Volcanic Phenomena.* — The crater of Kilauea took eight years for filling 400 to 500 feet of its depth preparatory to the eruptions of 1832 and 1840; and it was as full again in another eight years; but, this time, owing to a decline of activity, for some reason, an eruption did not occur. In the case of the summit-crater of Mount Loa, three great eruptions have taken place with intervals of $3\frac{1}{2}$ years, and six in the course of 25 years.

(5.) *Cinder Cones rapid in formation.* — The ejections of cinders are often very copious, and the cone, or several along the line of a fissure, may grow to a height of hundreds of feet in a few days.

(6.) *Eruptions of Lavas usually through Fissures.* —Volcanic mountains are not often strong enough to stand the pressure of liquid lavas carried up to the very brink of the crater. Hence, a volcanic mountain is intersected by great numbers of dikes. Mount Loa, although twenty miles in breadth only 1,800 feet below its top, has now no summit overflows, but becomes fractured by the eruptive forces, and so discharges its lava-floods. And usually the whole course of a stream of lava is the course of a supplying fissure. It is probable that Kilauea began in the opening of a great fissure at a Mount Loa eruption.

Owing to eruptions through fissures, tufa and cinder cones often occur in lines over a volcanic mountain. A fissure may continue its ejections at its widest parts long after its general outflow has ceased, and end in throwing up cinders. But the fissure, and not the subordinate cones, gives out the chief part of the ejected lava.

It is a remarkable fact, shown by the relative amount of degradation in the mountains, that the western end of the Hawaiian series of islands has been longest extinct; and so also the western or northwestern volcano of several of the islands, as in the case

of Oahu, Maui, and Hawaii, which consist each of two or more united volcanic mountains. At the southeastern end of the group occur the most recent lavas, and the only active fires. The opening of Kilauea was in this direction, and the southeastern part of Hawaii is the region of most of its recent eruptions. Fissure-eruptions began the group, and its volcanoes mark where the rents remained open. (See author's Rep. Geol. Expl. Exp. 281.)

The Val del Bove is a gorge or valley, with precipitous sides, 1,000 to 3,000 feet high, in the upper slopes of Mount Etna. Fresh-looking lavas cover the bottom; and dikes intersect the sides. It has been regarded as the result of subsidence. It is probable, as suggested by the author in his Report on Volcanoes, that at its head was once a crater, like Kilauea or the summit-crater of Maui. The conditions within and about the great depression accord with this view.

(7.) *Slopes of Lava Cones dependent partly on the position over the Mountain of the chief part of the Fissure-eruptions.* —If such eruptions are most common about the base they widen it, and thus southeastern Hawaiian has been widened nearly a score of miles beyond the true base of Mount Loa, this part having a pitch of only a degree or two. But if fissures for large eruptions are opened continuously in the upper part of the mountain, they tend to increase the pitch.

(8.) *Vibrations in the Rocks of a Volcanic Region.* — These are of three distinct sources. *First*, there are the tremors of a boiling cauldron, dependent on the escaping vapors of the open vent, which are ordinarily light at Kilauea, but often appreciable in regions of viscid lavas like Vesuvius. *Secondly*, vibrations come from those movements of the volcano which produce fractures: either (1) the abrupt production or condensation of steam; or (2) hydrostatic pressure; or (3) underminings of a region and subsidences. *Thirdly*, they may have their source in former general movements of the earth's crust. See page 804. The microphone is now used for the study of the vibrations of the volcanoes of Italy, and makes records even of the faintest mutterings of the crater.

(9.) *Volcanoes situated in close proximity, independent in their Eruptions.* — In the case of the summit crater of Mount Loa and its lateral pit, Kilauea (20 miles distant), each is an active crater of the first magnitude; and, further, the two belong to the same mountain dome; and yet the lavas stand in one conduit, at the time of a summit eruption, nearly 10,000 feet higher than they do in the other. The two conduits are apparently branches of a common syphon; but this absence of sympathy shows that the union, if there is any at the present time, is very deep below and much obstructed, or else that the lavas in the two legs are of very unequal weight through the vapors present or otherwise.

Kilauea, although nearly four square miles in area, cannot prevent eruptions at the summit of Mount Loa; and if so, *volcanoes, however large, are very poor "safety-valves."* A country is safer without them.

2. Non-volcanic Igneous Eruptions.

Non-volcanic igneous eruptions are those that take place through fissures, in regions remote from volcanoes. The modes of eruption are not essentially different from those of true volcanic regions. The cooled rock occupying the fissure is called a *dike*, as explained and described on pages 107, 112; and the dikes vary in width from a foot or less to hundreds of feet.

These eruptions have occurred on various parts of all the continents, but especially along their mountainous border-regions. Examples in the Lake Superior region are mentioned on page 185; in Eastern America, on page 418; in Western, page 524. Along Snake River, the southern fork of the Columbia, a single field covers 24,000 square miles; and in Oregon, on the upper Columbia, another has an area of 30,000 square miles, or, with the Mt. Hood region included, 40,000. In India, the great basaltic area of the Deccan covers 200,000 square miles. Areas are very numerous in western Great Britain, especially in Cornwall, Wales, and portions of Scotland and Ireland. Fingal's Cave and the Giant's Causeway are noted examples.

The fissures for the ejections were formed by a fracturing of the earth's crust, down to a region of liquid rock. They have thus the same origin as volcanoes, — but with this difference: that the fissures did not remain open vents for successive outflows.

The columnar form which the rocks often assume — not unfrequent in volcanic regions — is well illustrated in the accompanying sketch (Fig. 1119) of a scene in New South Wales.

Fig. 1119.

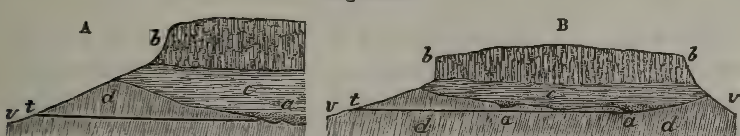
Basaltic columns, coast of Illawarra, New South Wales.

The rocks include nearly all the igneous rocks mentioned on pages 76–79, except the scoriaceous and glassy kinds; and even the latter occur at times in forms like pearlstone and tachylite. The heavy basic

rocks, doleryte and peridotyte, and the lighter feldspathic or acidic kinds, felsyte and others allied, are the most common. They are sometimes cellular, owing to inflations by steam or other vapors; but the cellules have generally a smooth or even surface within, and are not ragged like those of lavas, — a fact due to their having been under pressure when formed. Such cellular kinds have the cellules filled with minerals of subsequent origin, and thus become the rock called *amygdaloid* (p. 66). The manner of filling these cavities, and the nature of the materials, are explained on page 777. Amygdaloidal varieties of dolerytic rocks usually contain considerable moisture, and often also disseminated chlorite. They thus show that they were subjected to a free supply of moisture, from a subterranean source, when in process of eruption; and this fact accounts for the existence of the cellules.

These igneous rocks sometimes form layers, interstratified with ordinary sandstones or other sedimentary rock, and even uncompacted sand and gravel; showing that they having flowed out over a region, it may be for hundreds of miles, covering up the strata previously laid down, and then becoming the basis for new deposits of sand or mud. They thus lie between beds in all the geological formations. Examples of American Lower Silurian igneous rocks of the kind are described on page 185. The Triassic or Jurassic trap, on the Atlantic border of North America, affords another example, as described on page 418; but the beds here have come up through sandstone rocks, without extensive overflows. The Cretaceous era, and still more the Tertiary and Quaternary, were remarkable for the extent of the eruptions over the western slope of the Rocky Mountains (p. 524), and also in Britain (p. 525) and many parts of Europe, and on other continents. The

Fig. 1120.



Sections of Table Mountain: A, at Maine Boys' tunnel; B, at Buckeye tunnel.

lava floods that spread over the western slope of the Sierra Nevada (p. 797), were so vast that, as Whitney states (Geological Report, 1865, and Auriferous Gravels, 1879), many river valleys were obliterated, and the rivers were forced to begin erosion anew along other lines. Although having only the Quaternary to work in, the mountain streams have cut up large parts of the lava-covered region into "table mountains," and dug their new channels, to a depth, in many cases, of 1,000 to 3,000 feet. The preceding figures, from Whitney,

are sections of Table Mountain, in Tuolumne County, California. They show the *old* now buried river valley (cut out of tilted Sierra schists, *d*), holding in the river bed (at *a*, *a*) auriferous gravel, and, above, finer fluvial deposits (*c*), which often are partly volcanic ash, and sometimes contain silicified stumps and logs; and, over all, the cap of basalt (*b*); *b v* is part of the outline of the adjoining *modern* valley. Tunnels (*t*) are made through the "rim-rock" of such old valleys to reach the gravel, the gold being collected in these bottom deposits because of its weight.

The following sketch, from Hayden's Report for 1873, represents "Gothic Mountain," in Colorado, in which a mountain mass of trachyte rests on a base of Cretaceous rocks. In this nearly horizontally

Fig. 1121.

Gothic Mountain, Colorado. A trachytic mass overlying Cretaceous rocks.

stratified base, near the top, there is an independent dike of the same rock, which was probably produced contemporaneously with the outflow making the mountain. The mountain is nearly 2,000 feet in height above the Cretaceous base, and 12,465 feet high above the sea-level. The rock is trachyte, — a porphyritic variety, — and, like that of many trachytic eruptions, is destitute, according to Hayden, of bedding or evidences of separate lava flows.

These eruptions through fractures are sometimes accompanied by deposits of tufa, made of the lava that was reduced to fragments or powder by the cold waters which the melted rock came in contact with, or by cinder ejections; and very often the beds of tufa consist of a mixture of volcanic sand and ordinary sand or earth.

Veins of minerals and ores are part of the results of these fissure eruptions, as explained beyond.

3. Heat of Lavas and Conditions of Igneous Action.

1. Temperature of Fusion. — The temperature of the lavas of large free-flowing craters in full action is often not less than 2,200° F. within 2 or 3 feet of the surface; and the feldspathic and augitic (or hornblendic) portions are in complete fusion.

The chrysolite and magnetite, present in much of the rock, are infusible minerals, and hence may be solid grains floating in the lava. The Eifel bombs are evidence that this was the condition in the vent whence they were ejected. But their condition below is uncertain.

(*a.*) The above statement as to the degree of heat is proved by facts at Kilauea. Over the great lake of lavas in the pit, in 1840, the play of jets brought into view the hotter lavas beneath them, and produced a brilliant spangling of white light. The jets were but 60 to 300 feet in height, and hence the white-hot lavas beneath, brought into view by the movements, were quite near the surface. This indicates a temperature of at least 2200° F. The heat is sufficient not only to retain the lavas in a melted state, but, should they become thickly crusted over, to remelt the hard crust (after first breaking and submerging it) and make it join in the boiling.

(*b.*) The fusion of the labradorite and augite, the chief constituents of the lava, was complete. The volcanic glass of Kilauea has the composition of ordinary doleryte. The mean of two careful analyses of the capillary variety (called Pélé's Hair), made in 1879 by Mr. T. J. Allen, gives Silica 50·75, Al_2O_3 16·53, Fe_2O_3 2·10, FeO 7·89, MnO *trace*, MgO 7·65, CaO 11·96, Na_2O 2·13, K_2O 0·56, ignition 0·35 = 99·92; which is almost identical with the composition of the Mesozoic doleryte of the Connecticut valley. This glass hence contains the feldspathic and augitic ingredients in complete fusion, and at a low temperature compared with that of the mass of lava; for the glass is from the superficial scum of the lava pool, the fibres being made by the transporting winds carrying off points from the lava jets.

Again: Plattner found, by comparing with the fusibility of alloys of platinum and gold, the fusing temperature of slags from iron furnaces to be 2430° F. to 2452° F.; and Mehrbach obtained, in a similar way, for an iron furnace slag containing 37 to 40 per cent. of iron protoxide (one of them near an iron-augite) 2400° F. to 2480° F.; and for another, near a scapolite, 2608° F. (Mehrbach's Anw. der Gebläseluft, Leipzig, 1840). These temperatures are to be taken as only approximations; but, with the largest allowance for probable error they sustain the above statements. [2016° F. was taken for the fusing point of gold, and 4593° F. for that of platinum.]

Further, labradorite and the ordinary augite of volcanoes have about the same easy fusibility, each being marked 3 on Von Kobell's scale; and the latter has often been obtained in crystals from furnace slags.

There is hence no reason for questioning the complete fusion of this part of the lavas. The fusibility of native silver is marked 2 to 2·5 by Von Kobell, and is 1904° F. according to determinations at the Utrecht mint in 1869.

(*c.*) The material of the soda-feldspars (albite, oligoclase) and potash feldspars (orthoclase, microcline), is also in complete fusion in many lavas. Most obsidian is essentially orthoclase in a glassy state; and at Lipari there are streams of this glass, with lines showing a sluggish flowing movement; and thus the above statement is true as far as orthoclase or its ingredients are concerned. Now orthoclase is the least fusible of the feldspars, being marked 5 on Von Kobell's scale (and microcline is the same); while albite is marked 4, and oligoclase 3·5. In an ordinary oven for baking porcelain, at Trenton, in New Jersey, albite (from Branchville, Conn.) was easily fused down, while the microcline of the same locality was only fused over the surface. The temperature of fusion of ordinary glass is not easy to obtain because it is plastic (or undergoes "vitreous fusion," as it is called) long before the fusion is complete.

The leucite of the Vesuvian lavas is an infusible mineral; and these lavas, near the surface, are in a half-fused or pasty state, having unusual viscidity. Experiments at Vesuvius have obtained for the flowing lava streams a temperature above the fusing point of copper as well as silver. Davy found that a copper wire one twentieth of an inch in diameter, and a silver wire of one thirtieth, when thrust into the flowing lava at Vesuvius, near its source, instantly melted. The copper indicates a temperature of 2426° F.; and this may be much less than that which exists a yard below the surface. At what depth in the volcano the leucite takes its solid form is undetermined. The crystals sometimes contain grains or crystals of augite, *showing that the augite crystallized first;* and, also, that the temperature at which they are formed may be no greater than that required for the augite. The mineral may come from the alteration of orthoclase in rocks adjoining the seat of fire, as it most resembles this species in constitution.

The view that the fusion of lavas is due to the combined action of moisture and heat, or is *aqueo-igneous*, was early presented by Scrope, and has been held by later writers. But while the steam present in them increases their mobility, it does not appear, in view of the above-mentioned facts, to be essential to their fusion and flow.

With decrease of temperature lavas may increase in viscidity in three ways: (1.) By a close approach to the limit of fusion, as in ordinary glass; (2.) by incipient crystallization of the ingredients, a pasty condition remaining because a portion is still in fusion, as happens with molten cast-iron; (3.) by the less fusible portion crystallizing, or becoming individualized, leaving a more fusible part to keep up a sluggish flow. When there is a slow decline in the activity or heat of a volcano, the overflows for a long period may generally consist of lavas that have reached a thickened or pasty state in one of these ways. Masses of lava thrown from the stream at the eruption of Kilauea, in 1840, caught around the branches of trees and clasped them, and with only a scorching of the bark, showing that though plastic they were previously half solidified. Orthoclase lavas pass most readily into this sluggish state because of their less fusibility, and sometimes make dome-like hills from the swelling up of the thickened, feebly mobile material, as in the extinct volcanic region of Auvergne.

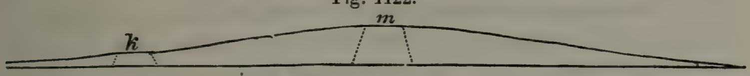
The semi-glassy lavas called rhyolytes, often show that the constituent minerals of the material become crystallized or individualized together even when different in fusibility. Thus in obsidians *belonites* and *trichites appear together*, as the first step toward lapidification; and, in a later stage, orthoclase and hornblende or augite exist together in the glassy base, with sometimes also a triclinic feldspar; and these increase, relatively to the amount of glass, as the passage to stone becomes more and more complete.

2. Conditions of volcanic and non-volcanic igneous action. — (1.) *Volcanic Action.* — This subject may be best illustrated by the facts afforded by the great Hawaiian volcanoes. The map on page 725 shows the positions of the two active craters, 16 miles apart; and the following section, the relation between the sizes of the craters and the height of the mountain. It is to be kept in mind that the lavas, previous to several eruptions of the summit-crater, stood about 13,000

feet above the sea-level, and previous to those of Kilauea, 3,400 feet; that the filling of the craters to the high-level mark had in each case gone on *quietly;* that the discharge of the lavas, at the eruptions (among the grandest on record) has usually begun and ended in a quiet way.

The clouds which constantly rise when the craters are in full action, and often drop rain over the region around, are evidence that water is present within the lavas in immense quantities. Sulphurous acid constitutes a very small portion of the escaping vapors. This water is

Fig. 1122.



Section of Mount Loa.

not salt-water; for chlorides are rarely met with among the products due to the vapors. It must come either from deep depths in the earth's crust, as urged by Scrope (first in 1825), or from the rains or superficial waters. Whether the former is one source or not, the latter must influence greatly the action. Rains fall abundantly over the windward (or eastern and southeastern) sides of the island, and make few surface-streams only because the rocks are so extensively fissured and cavernous. Of the water that becomes subterranean, part follows the sloping beds seaward; but another part must reach the region of the fires, and after being changed to vapor by the hot rocks about the conduit, pass into the liquid lavas, being forced to this because there are no sufficient passages for the escape of such volumes of vapor or gas. Ehrenberg's observation that the cinders of volcanoes all over the globe *contain large numbers of fresh-water infusoria* (*Diatoms*, etc.), supports the view that fresh waters are commonly the working agent.

The moisture absorbed, or present in the lavas from any subterranean source, has a temperature above 2,200° F. (for, if this degree exist at surface, a higher must exist below), and is under a pressure of 85 to 95 atmospheres for every 1,000 feet of depth. The superheated steam taken in is forced upward by the heavy lava; and as it rises, it expands with the diminution of pressure, enlarging the mass of liquid material and thereby increasing its height in the conduit. The steam thus makes its way to the surface. At the surface, the cohesion of the lavas, increased by incipient cooling, detains the bubbles of steam until they are so large and the crust so thin that the steam is able to overcome the resistance; they then burst, producing the jet of fragments, which are liquid lava as they rise, and still liquid enough at Kilauea on falling to adhere firmly to the solid rim of the lava-vent.

The moisture must hence continue to be at the high temperature of fusion or semifusion until the final escape.

Further: Through the action described, the column of liquid lavas is lengthened upward ultimately some hundreds of feet. This exposes a far larger surface and amount of liquid lava to the waters of the island, and in a more accessible condition. The action becomes consequently more rapid and vivid, the escaping vapors more abundant, the floodings of the crater's bottom more frequent, with greatly enhanced risks of catastrophe from any sudden supplies of water. Finally, owing to the augmented pressure of the lava-column, and the pressure of the vapors seeking escape, a break occurs, and a discharge.

Prévost compared the rise of the lavas in a volcano and the overflow to the frothing over of a molasses cask at the bung-hole; and the illustration is instructive.

Rev. Titus Coan, to whom science owes much for his observations on the Hawaiian volcanoes, states that during the months previous to the violent eruption of 1868, when the summit-crater and Kilauea were in simultaneous action, and the island was convulsed with earthquakes, there had been unusual rains, and he attributes to this fact the unusual violence of the eruption; and it has been observed elsewhere that rainy seasons are most favorable to eruptions.

In volcanoes with more viscid lavas, like Vesuvius, the course, as the facts described on page 733 show, is in general the same; but the resistance to the escaping vapors, due to the viscidity of the lavas, is vastly greater; and, consequently, the liability to fracture when an eruption is near at hand,—so giving access to the sea or some subterranean fresh-water streams — makes such volcanoes more liable to catastrophic eruptions. It also gives the cones steeper sides, and, therefore, less strength for resisting fracture.

What proportion the moisture from the deep source of the lavas of a volcano bears, in volcanic action, to that from superficial sources it is not possible to say. The *former* may be a constant force causing upward movement, and a supply of heat and lava, and so act against the cooling influence of superficial waters; the *latter*, a cause of the daily and yearly variations of condition, and of the eruptions.

Deville has presented the view that *hydrogen* from the dissociated elements of water, is an essential agent in volcanic action; and essentially this view was held by Delanoüe, Angelot, and Elie de Beaumont. It is not yet sustained by facts from the emanations which come direct from the volcanic focus, nor by any peculiarities in the lavas, such as would arise from the oxygen that should in that case have been free to enter into new combinations.

(2.) *Non-volcanic Igneous Ejections.* — The wide extent of the outflow of igneous rocks in some non-volcanic regions appear to indicate that the areas of fusion beneath the earth's surface have often had

very wide limits. The Mesozoic eruptions of doleryte ("trap") on the Atlantic border of North America show by their extent (p. 417) that the source of liquid rock was not less than a thousand miles in length from northeast to southwest; or else, that isolated areas existed at the time corresponding to the principal areas of eruption, the Nova Scotia, the Connecticut valley, and each of the more southern from New Jersey to the northern border of South Carolina, — a view not probable considering the uniformity in constitution of the trap throughout.

They teach also that other forces have produced ejections to the surface besides those that work in the throat or conduit of a volcano. For the ascent of the liquid rock cannot depend on the slow ascension of expanding gas or steam within it, the outflow from fissures being usually as sudden as the fissuring. Two other agencies are appealed to: The pressure (1) of vapor (steam) in the deep subterranean region of the lavas; and (2) of the earth's crust upon the liquid mass below. The first mentioned source of ejecting force, has its limit, as explained by Bischof (in 1839), in the fact that "the elastic force of steam cannot surpass a certain maximum which it reaches when its density is equal to that of water." Using the formula of Mayer, he deduced for this limit in pressure nearly 8,320 atmospheres, which corresponds, he observes, to a temperature of 2,786° F. and, for the height of the column of lava, of specific gravity, 3·0, which steam at its maximum elasticity is capable of supporting, 88,747 feet, or less than 17 miles. Experiments have not been carried far enough to make such calculations even approximations; yet they show that there is undoubtedly heat enough for the best that steam can do. But this elastic force of steam is that of *saturated* steam, and it demands that a constant and full supply of water be kept up—a condition not possible in the depths of the earth, unless the sea enter freely, which is not at all probable, and not indicated by any products along the walls of dikes. It is not even certain that there is much if any moisture in the plastic depths of the globe (p. 814).

The second cause, pressure of the earth's crust, may have often been sufficient, and the actual cause. The fact that the melted rock has been pushed upward with great force, as if from such pressure, is sometimes apparent in the displacements or increased dip given to beds adjoining fissures, especially in cases of oblique fractures. Upliftings take place from this cause in volcanic regions; and the pressure of escaping vapors contribute to the effect, these vapors opening chambers into which the melted rock is forced and becomes congealed. Such vapors may have often aided also in fissure-ejections intersecting sedimentary strata, since these always contain moisture and may include subterra-

nean streams; and the force from generated vapors may work with that from pressure below in producing uplifts of an adjoining region.

As subterranean waters from superficial or other sources are taken in by the lavas of volcanoes, so may they have been by the igneous material filling fissures, wherever it was accessible to them while it was on the way to the surface. When a fissure intersects sedimentary strata it may encounter subterranean streams of water of great volume, and become thoroughly penetrated by it. Having no open throat to escape by as in a volcano, the moisture, in the form of steam, may saturate the rock, hydrating more or less its minerals, turning pyroxene to chlorite, feldspar to zeolites or chlorite, and making other alterations, besides causing steam-holes or the so-called amygdaloidal cavities — where the pressure admits of it. So again if limestones are encountered, carbonic acid may be taken in for making, along with the lime of the pyroxene or feldspar, calcite amygdules. Even the mineral oil of carbonaceous shales was taken up in the gaseous state by the trap of the Connecticut valley and deposited in an oxydized condition in the amygdaloidal cavities, where it now occurs in black coal-like nodules. The zeolites of amygdaloids, page 777, are other results of this kind of action.

3. Chronological variations in igneous action. — As to the kinds of igneous rocks, the past and the present are essentially the same. The acidic and basic bear to one another about the same ratio, and have the same composition. Felsyte of the Silurian is identical in mineral composition with the trachyte of modern times, the older doleryte with the most modern, the older dioryte with the modern propylyte and quartz-propylyte, and so on. But in the earlier periods, eruptions were fewer, and mostly through fissures and non-volcanic; in the later, largely volcanic as well as non-volcanic. Volcanoes appear to have been produced in great numbers in the Tertiary, and had then their greatest eruptions. The augmented elevation of the continents during and since the Tertiary may have been one cause of their decline in activity.

In a given region, feldspathic (orthoclase or acidic) igneous ejections have generally preceded dolerytic (basic). On this view their frequent occurrence at the centre of volcanic mountains has usually been explained. But they have sometimes succeeded to dolerytic eruptions, as Lyell observed in Madeira.

Titles of some of the works and memoirs on Volcanoes and Volcanic phenomena: —

G. P. SCROPE: On Volcanoes. 8vo, London; 1st edit. 1825, 2d edit. 1862. In both editions attributes fluidity in lavas to aqueo-igneous action, and presents the view that "the originating cause of eruptions and changes of level in the crust is the unequal transmission through it of heat from beneath, owing to variations in the covering surfaces from the deposition of sediments," "and the abrasion of the land." — Geology of

Central France, 1826, 1827. — On the Formation of Craters and the liquidity of lavas, Quart. J. Geol. Soc., xii., 326, 1856.

C. LYELL: Principles of Geology, 2 vols. 8vo, London. The last edition in 1872.

L. VON BUCH: Physikalische Beschreibung der Canarien Inseln. Berlin, 1825. (Also published in French.) — Sur les Cratères de Soulèvement et les Volcans, Bull. Soc. Geol. de France, ix., 355, 1838.

C. PREVOST: On Volcanoes, Bull. Soc. Geol. de France, xi., p. 188, 1840. Notes sur l'Île Julia, pour servir à l'Histoire de la Formation des Montagnes Volcaniques, Mem. Soc. Géol. de France, ii., 1835. The Julia Island is the same with Graham Island (p. 736). All the memoirs of Prevost are remarkable for their judicious views.

ÉLIE DE BEAUMONT: Recherches sur la Structure et sur l'Origine du Mont Etna, Comptes Rendus, i. 429, 1835, and Mém. pour servir à une Description Geol. de la France, vol. iv. 1838. Note sur les Emanations Volcaniques et Metallifères; Bull. Soc. Geol. de France, II. iv., 1249, 1847; the distinction of *acidic* and *basic* igneous rocks here first formally announced, though earlier recognized by De la Beche.

BOUSSINGAULT: Chemical Researches on the Gases of the Volcanoes of Ecuador, Ann. Ch. Phys., lii., 5. Ascent of Chimborazo, ibid., lviii., 150, 1835.

G. BISCHOF: On the Natural History of Volcanoes and Earthquakes. Edinb. New Phil. Jour., xxvi., 1839, and Am. J. Sci., xxxvi., 230, 1839.

R. BUNSEN: Ueber die Processe der vulkanischen Gesteinsbildungen Islands. Pogg. Ann., lxxxiii., 197, 1851.

C. ST. CLAIRE DEVILLE: On Volcanic Emanations, Comptes Rendus, 1856, 1857, 1862 (with Le Blanc and Fouqué, on Hydrogen of Volcanoes).

M. FOUQUÉ: On Eruptions of Etna in 1865, Comptes Rendus, 1865.

C. DARWIN: On Volcanic Islands (from observations made during the voyage of the Beagle), 8vo, London, 1844.

J. D. DANA: Observations on the Volcanoes of some Pacific Islands, including the Hawaiian Islands, and on Igneous ejections in Australia, with general conclusions on volcanic phenomena, in Geol. Report of Wilkes's United States Exploring Expedition, 1849.

J. W. JUDD: Contributions to the Study of Volcanoes. Geological Magazine, II., ii., iii., 1875, 1876.

4. THERMAL WATERS, GEYSERS.

The subject of thermal waters constitutes an important part of Chemical Geology, and is here only briefly treated.

Hot springs are common (1) in volcanic regions, and occur also (2) along the courses of non-volcanic eruptions; they are occasionally met with, away from all igneous eruptions, (3) on the lines of faults or the axes of flexures, and sometimes (4) where there are none of these conditions. The heat in the first two cases is generally of volcanic, or deep subterranean, origin; but in the others, it may come from the oxydation of sulphids, or from other chemical action, in the rocks or earth beneath.

When the temperature is high the waters may be either essentially pure, or strong mineral solutions. The waters often hold silica in solution, whose deposition, over the region around, makes irregular accumulations of a coarse opal, or rarely of quartz, and forms low cones or rims about basins. Occasionally, the waters are calcareous, instead of siliceous, and make calcareous basins or cones. The sources of such solutions, and some of the effects resulting from them, are explained on page 706, and beyond.

Iceland has long been noted for its geysers; but it is far outstripped by the region of the Yellowstone Park, explored and mapped by the expeditions under the charge of Dr. F. V. Hayden. This locality is situated about the head-waters of the Yellowstone and Madison, two tributaries of the Missouri, and of the Snake River, a tributary of the Columbia, at heights of 6,500 to 8,000 feet above the sea-level. The geysers, which are mostly about the Fire-Hole Fork of the Madison, and near Shoshone Lake at the head of Lake Fork of the Snake, are exceedingly numerous, and play at all heights, up to 200 feet, or more; and, besides, there are multitudes of hot springs of various temperatures, the most of them between 160° and 200° F., the boiling-point of the region being 198° to 199° F. All together, the number of hot

Figs. 1123–1125.

GEYSER-CONES. — Fig. 1123, Giant Geyser; 1124, Liberty Cap; 1125, Beehive Geyser.

vents in this region cannot be less than 10,000. But the region is far from fully explored; and the geyser-areas east and southeast of Yellowstone Lake, recently reported, may double this number.

The hot waters of the Fire-hole Fork of the Madison and of the Shoshone Lake region are siliceous, while those of Gardiner's River, a tributary of the Yellowstone, are calcareous. Some of the forms of the geyser-cones are shown in the accompanying figures. Fig. 1123 represents the cone of the "Giant" Geyser, in the Upper Geyser Basin of the Fire-hole; it is about ten feet high and twenty-four feet in diameter at base, and has one side partly broken down and bent inward. It throws out, at long intervals, a jet ninety to two hundred feet in height. The "Beehive" geyser-cone (Fig. 1125), of the same region, is small, being but three feet high and five in diameter at base; but its jet, shown in Fig. 1126, as it appears when in full play (from an excellent drawing by Mr. Holmes), is one of the highest, it exceeding two hundred feet. It plays about once a day. Fig. 1124 represents the "Liberty Cap," one of the calcareous geyser-cones of the Gardiner River region, now extinct; it has a height of fifty feet, and a diameter at base of twenty feet. "Old Faithful" is one of the largest of the Madison River geysers; it has a low and broad irregular cone, and throws up its great jet to a height of one hundred and thirty feet, once in about sixty-five minutes, the remarkable regularity of its action having suggested the name it bears. The "Giantess" is another of the large geysers of the Fire-hole; the basin has a breadth of twenty-three and a half by thirty-two and a half feet, and holds sixty-three feet in depth of water, and at intervals throws the whole to a height of sixty feet. Another, the "Architectural" geyser, is actually, when in action, a combination of jets of all sizes and angles of inclination, each having some independence in its movements, but all working together, and hence producing a marvellous effect from the ever-changing views.

Frank H. Bradley, of the expedition under F. V. Hayden, in 1872, observes that,

while standing on the mound of "Fountain" geyser, whose pool was overflowing, and watching a steam-jet of a hundred yards away, the jets suddenly ceased, and "Fountain" commenced, throwing up a jet, ten feet in diameter, to varying heights, from

Fig. 1126.

Beehive Geyser in action.

five to forty feet. In thirty minutes, "Fountain" stopped suddenly, and immediately the steam-jet began again; in twenty minutes more, the jet again stopped, and at once a small pool, a few yards from "Fountain," which was empty when that was playing, but had become partly filled from its overflow, began to boil and throw up water to a height of five or ten feet, and continued this for half an hour; as it moderated, the steam-jet opened anew, but ceased when the boiling became more violent. The

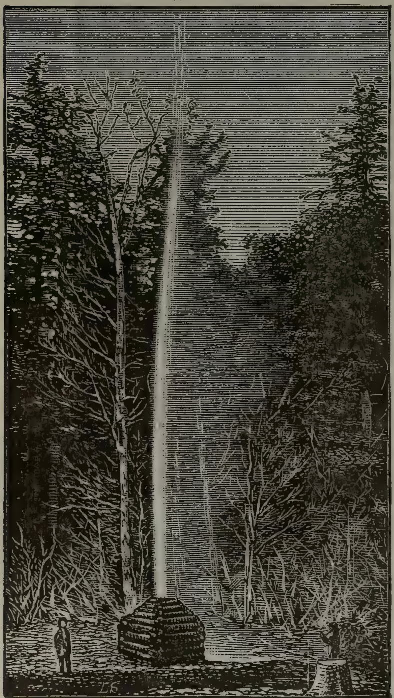
facts prove a sympathy between different vents; and the same was illustrated in other parts of the region.

Bradley also states that, during the eruption of some of the larger geysers, there are pulsating sounds or thumps, in the depths of the geyser conduits, which have no parallel movement in the jet; and that, in an eruption of the "Giantess," there were seventy-three of these pulsations a minute; and in that of "Grand" geyser, at first seventy-two or seventy-three, but in the course of twenty minutes they decreased to seventy, and became gradually fainter.

These and other geysers, and additional hot-spring phenomena, are described in the Reports of the expedition under Hayden for the years 1871 and 1872.

The siliceous geyser-cones are all beautiful concretionary work; and the beauty of form and texture and pearly lustre is often greatly enhanced by the delicate shades of pink, buff, yellow, and other tints, mingled with white, over their surfaces. Pebbles, in the bottom of the small basins formed about the cones, are commonly concretions of the opal, like the rosettes of the bottom and sides.

Fig. 1127.



Water-and-gas Geyser.

In the eruption of a geyser, the jet is first water; then much steam with the water; and, at last, mostly or wholly steam, the water having been all thrown out; and, when the water partly falls or runs back into the basin, the eruption is sometimes renewed successively, before finally stopping.

The action of geysers is owing (1) to the access of subterranean waters to hot rocks, producing steam, which seeks exit by conduits upward; (2) to cooler superficial waters descending those conduits to where the steam prevents farther descent, and gradually accumulating, until the conduit is filled to the top; (3) to the heating up of these upper waters by the steam from below, to near the boiling point; when (4) the lower portion of these upper waters becomes converted into steam, and the jet of water or eruption ensues. This is nearly the explanation given by Bunsen. The deposit of silica in the throat of the conduit, after an eruption, tends to diminish its size, and sometimes closes it completely, so that the waters are obliged to open a new vent.

Hot springs also occur at many other points in, and west of, the Rocky Mountains. There is a region of springs of hot water and

steam in California, north of San Francisco, in Geyser Cañon, a branch from Pluton Cañon. The waters have a temperature, according to Whitney, of 206° to 207°; and deposits of sulphur are formed from them. Near Clear Lake, in Lake County, there is a "Borax lake," holding borax in solution, and having a deposit of it, over its bottom; and, as Whitney observes, it is evidence of the action of hot waters in former times. Other borax lakes occur at Lick Springs, Tehama County, California, and in Esmeralda County, Nevada. Boracic acid is held in solution in the hot waters of the Tuscan lagoons.

A *water-and-gas* geyser exists in the oil region of Western Pennsylvania (in the valley of Wilson's Run, four miles southeast from Kane), in which hydrocarbon gas, and not steam, is the moving agent; and it is called the Kane Geyser. The accompanying figure (Fig. 1127) is from a photograph received by the author from Mr. C. A. Ashburner, accompanying a description by him of the geyser. The well descends to a depth of 2,000 feet. It throws out a column of water and gas periodically to heights varying from 100 to 150 feet — the interval being, in the summer of 1879, about 13 minutes. The gas of the columns is often lighted at night and "the antagonistic elements of fire and water are promiscuously blended, at one moment the flame being almost extinguished, but only to burst forth the next instant with increased energy and greater brilliancy." Mr. Ashburner explains the action thus: "The water flows into the well on top of the gas until the pressure of the confined gas becomes greater than the weight of the superincumbent water, when an explosion takes place and a column of water and gas is thrown to a great height." The gas comes from the deep-seated rock that has yielded also the oil, and some higher temperature than that of the surface was needed for its production.

The distinction between *cold* and *warm* mineral springs is of very little importance. The waters derive the chief part of the salts in solution from the alteration of the rocks or minerals within their reach. The soda and potash, yielded by the feldspars of granites and various other rocks when these are acted on by means of carbonic acid, produce carbonates for such waters; and when rocks are decomposed by sulphur acids sulphates (alums, etc.) may result. Limestone decomposed by an acid yields carbonic acid, to give waters "briskness," and help make chalybeate waters; or to combine with other mineral ingredients soluble or insoluble, and produce other kinds of mineral waters. The carbonic acid and sulphur gases for such results may also come from the decomposition of vegetable or animal material. Nitrogen may become a bubbling gas of a mineral spring through the absorption of the oxygen of the atmosphere of the earth beneath by means of organic matters (pp. 704, 705); and sulphuretted hydrogen make "sulphur springs" through decomposing pyrites (p. 705). The mineral waters of the region of Saratoga rise from a depth of more than 600 feet, borings to this depth, as Chandler observes, having afforded similar waters: and hence they come from the underlying Potsdam sandstone. They contain calcium, magnesium, sodium, and iron bicarbonates, and sodium iodide and bromide, along with free carbonic acid, and some common salt, besides traces of other ingredients.

4. METAMORPHISM.

1. General Characteristics.

Metamorphism means *alteration* in rocks; alteration as to texture, and often also as to mineral constitution; alteration affecting strata over wide regions at the same time. The sedimentary rocks described on pages 67–69, as sandstones, shales, conglomerates, even coarse conglomerates, and limestones, are the rocks that have thus been changed; and the crystalline kinds, called metamorphic rocks, described on pages 70–75, for example, argillyte or roofing slate, mica schist, gneiss, much granite, crystalline limestone or marble — are some of the results. But there is no obvious line of division between the unaltered and the altered or metamorphic rocks; the changes are of all degrees, and consequently the two kinds pass into one another by insensible gradations.

For a time after geology had begun to be a science, granite, gneiss, mica schist, were called *Primary* rocks, under the idea that they were the oldest. But now it is known that such rocks, although to a large extent Archæan or Paleozoic, may be of any period of origin.

Metamorphic rocks may have undergone in whole, or in part, a second alteration or metamorphism; for no condition of the earth's terranes is free from liability to change.

A single metamorphic region, that is, a region of simultaneous metamorphism, often covers tens of thousands of square miles, and its altered rocks a depth of many thousands of feet. The operation has, therefore, much of the geographic comprehensiveness of mountain-making; and in fact, it has usually been one of the consequences of the profounder movements of the earth's crust. But while generally thus wide-reaching, it has also occurred in a more limited way; and many local changes that have taken place are of the same nature with the grander metamorphic changes.

Some examples of wide regional metamorphism have been described on pages 151–156, 213, and 400; and the facts there related are a proper introduction to the following discussion of this subject. The reason for believing in *regional* metamorphism is there presented — that the crystallized or metamorphic rocks in some parts of the metamorphic region, and especially on its borders where the action is less complete, are found to graduate into ordinary sedimentary rocks, and also to contain more or less perfect traces of the fossils that filled many of the beds. Thus, in the case of the Green Mountain region, in which a crystalline limestone, with conformable schists and more or less of quartzyte, extends from Western Connecticut and the adjoining part of New York to and beyond Rutland, Vt., the limestone contains fos-

sil crinoids, corals, and shells along part of the West Rutland Valley, along a portion of the belt between two ranges of marble quarries, and at other points in Vermont, and also to the south, in Dutchess Co., New York. Similar evidence has been observed at Lake Memphremagog, at Bernardston, Mass., in the Sierra Nevada, in Cornwall, in France, Norway, the Urals, the Tyrol, the Alps, and in many other regions. At Brevig, Norway, a Silurian limestone with fossils contains also garnets and scapolite; in the Urals, Murchison found a crystalline limestone containing encrinites; schists in Brittany are described by Boblaye as affording andalusite crystals and species of *Orthis*, *Spirifer*, and *Calymene*, in one and the same specimen; at Rothau, in the Vosges, in a hornblende rock, corals have been replaced, as stated by Daubrée, without losing their form, by crystals of hornblende, garnet, and axinite; among the corals the species *Calamopora spongites* is quite distinct. In view of such facts, the fact of regional metamorphism is no longer a mooted question.

2. Effects of Metamorphism.

The principal effects of Metamorphism upon rocks are the following: (1) Consolidation; (2) Loss of water or other vaporizable ingredients; (3) Loss of material by chemical solvents; (4) Change of color; (5) Obliteration of fossils; (6) Crystallization without a change in the combinations present; (7) Crystallization with more or less change in the constituent minerals of the rock.

1. *Consolidation.* — Ordinary atmospheric or subterranean waters, however prolonged their action, do not necessarily produce solidification. The soft sandstones of all ages, from the Potsdam to the incoherent beds of the Quaternary, are evidence on this point. It is probable that deposits have existed to an immense extent in past time, that failed to be consolidated, and consequently were washed away in the course of subsequent changes.

But while there are many fragile Potsdam sandstones, there are others, as those of eastern New York and Vermont, that have been hardened, through some process, into quartzytes and quartzose gneisses, and deposits of sand and pebbles of various other ages that are refractory sandstones and grits. That the consolidation is due to circumstances of a metamorphic nature is often evident from their position within, or on the outskirts of, regions of other metamorphic rocks. In the same way, fragile absorbent argillaceous shales have been hardened into firm non-absorbent slates.

At the Geyser region of Yellowstone Park, according to F. H. Bradley, the sand-beds of a terrace on Shoshone Lake, over a hundred feet high, have been firmly consolidated, so as to look like quartzyte; and this was done by the hot siliceous waters, when the waters of the lake stood at a higher level.

2. *Loss of Water or other Vaporizable Ingredients.* — The *water* contained in the original material of a rock is sometimes wholly, and sometimes but partly, expelled. Gneiss, granite, and mica schist, are examples of the former; hydromica schist, chlorite schist, and serpentine, of the latter. The volatile portions of bituminous coal have been wholly or partly driven off by the process, and anthracite and semi-bituminous coal formed (p. 400).

Carbonic Acid is expelled from carbonate of lime, or limestone, as is well known, in a heated lime-kiln. But, in the metamorphism of limestone, it is retained. It has been shown by experiment that the carbonic acid is not given out, if the material is under heavy pressure. If this be true of carbonic acid, it will be so also of other ingredients less easily expelled.

3. *Loss of Material by Chemical Solvents.* — Limestones suffer most in this way, often losing much of their thickness, as recognized by Lyell, and, since the foreign ingredients are mostly left behind, the beds become by the process increasingly impure.

4. *Change of Color.* — Rocks of black, gray, and other colors, have been altered to white, grayish-white, and clouded gray, as in the change of limestones to marble; those of brown and yellow, and sometimes black kinds, to red; those of green, brown, and other shades, to black.

5. *Obliteration of Fossils.* — This fact has already been illustrated by examples. In the progressing obliteration, the fossil generally becomes flattened or distorted, and indefinite in outline, and finally is reduced to a patch of white crystalline limestone.

6. *Crystallization without a Change in the Combinations present.* — The Carrara marble, the marble of Rutland, and other pure crystalline limestones, have undergone in their metamorphism, no change of composition, but only that of *crystallization.* The same is true of the purer crystalline magnesian limestones, or dolomite. Some sandstones are made up of *pulverized* granite or gneiss; and if changed to granite or gneiss by metamorphism, as has often happened in such cases, the process would be simply one of crystallization. The steps and the result are analogous to those in the tempering of steel (p. 627), where the crystalline texture is changed from coarse to fine or the reverse. The beds of hematite (Fe_2O_3) of Archæan rocks may be simply the dull-looking earthy hematite beds of sedimentary formations crystallized.

In the metamorphism of common limestone, another change takes place besides that in the texture, which at the same time is not a change in the elements present, although it is one in the *mineral* nature of the material. Ordinary compact limestone, being made from pulverized shells, corals, or other *organic* secretions, has its calcium car-

bonate mostly in the state of *aragonite*, which differs from calcite in having one thirteenth higher specific gravity, greater hardness, higher specific heat, prismatic crystallization, and no very distinct cleavage. In its metamorphism, as stated by Sorby, the grains become calcite, and the rock then glistens with cleavage surfaces. It is in this change that fossils lose distinctness of forms; and only a slight degree of it will accomplish the result, since it changes every grain in the fossil.

7. *Crystallization with Changes in the Constituent Minerals of the Rock.* — In a large part of metamorphism, chemical forces have had an opportunity to make new combinations (1) out of the ingredients of a sedimentary rock; or, less commonly, (2) out of these and some introduced ingredients. While the feldspar and quartz of metamorphic rocks may often have existed as such in the rock before alteration, other minerals, including numerous kinds disseminated through the mass, are results of chemical change in the ingredients present. Mica, pyroxene, tremolite, garnet, scapolite, and various other species have been made, in the metamorphism of a limestone, out of its impurities; and so with the garnets, staurolites, and many common species, in the case of other rocks. Again, great beds of the magnesian silicate, serpentine, have been made by the alteration of beds of chrysolite, as in North Carolina, water being the only new ingredient needed.

3. Origin of Metamorphic changes.

The agencies concerned in the metamorphism, influencing chemical and crystallizing forces, are: (1) *Heat;* (2) *water* or moisture; and, in some cases, (3) mineral ingredients derived, either in solution or vapor, from outside sources.

1. Regional Metamorphism.

1. Temperature. — The heat causing regional metamorphism was, in general, (1) below that of fusion or plasticity; for most metamorphic rocks, like gneiss and mica schist, have not lost the original bedding. This is shown by the schistose structure, since it usually corresponds with the bedding or the lamination the rock had before its alteration. (See page 794.)

The heat was (2) sometimes sufficient to produce plasticity. For (*a*) a passage of gneiss into granite may be often observed, in which the bedding of the former disappears wholly in the course of a few yards or rods; (*b*) masses of an associated rock are sometimes involved in the granite, showing that the beds had been kneaded together while in the plastic state; and (*c*) fissures have been filled by the plastic granite. The passage of gneiss into granite is often thus, as the author has observed at several places in Connecticut: the hard

feldspathic gneiss, which usually has nearly straight lines of bedding (or, of schistose structure) appears with these lines much flexed; then, in a complete zigzag, and on so small a scale that the hand can cover the whole breadth of a flexure, — a condition indicating that there had been a close approach to plasticity; then, beyond, the lines of bedding are all gone, and the rock is well characterized granite, sometimes only for a few rods in extent, but sometimes for hundreds. The best of architectural granite has had this origin.

(3.) The heat for most metamorphic results was probably comparatively low, or between 500° F. and 1200° F. It was heat (4) in slow and prolonged action, operating through a period that is long, even according to geological measure. A low temperature, acting gradually, during an indefinite age — such as Geology proves to have been required for many of the great changes in the earth's history — would produce results that could not be otherwise brought about, even through greater heat.

The lower limit of temperature is sometimes placed much below 300° F.; and for consolidation it may be rightly so. But there is definite evidence that it generally exceeded this. In the great faults of the Appalachians, 10,000 feet or more in extent, Lower Silurian limestones are brought up to view, containing their fossils, and not metamorphic; and in Nova Scotia the coal formation, though 15,000 feet thick, is not metamorphic at base. Taking the increase of temperature in the earth's crust at 1° F. for 60 feet of descent, 10,000 feet of depth would give 220° F. as the temperature of the limestone before the faulting; and 1° F. per 60 feet of descent must be short of the rate that obtained in the Carboniferous age.

2. Moisture. — The fact that moisture was concerned is evident from the inability of dry rocks to become heated without its presence. Dry rocks conduct heat badly. Even a foot of fire-brick will confine almost all the heat of a furnace, and a yard of solid lava as completely the heat of the melted rock underneath. The presence of moisture has further been demonstrated by microscopic investigations of the metamorphic rocks themselves; for as Sorby showed, water is common in minute cavities in the quartz, garnet, and some other minerals of these rocks, and besides, as a result of the subsequent cooling, vacuities occur with the water. Crystals of quartz containing water in this way could not have crystallized from a state of fusion.

The moisture engaged in producing the metamorphic changes was for the most part that which existed in the sedimentary formation, either (1) permeating the rock, or (2) confined between its layers; so that the heat found the moisture which it needed for its diffusion and for metamorphic work *within the strata themselves.*

The average amount of moisture present in uncrystalline rocks, as limestones, sandstone, shales, is over 3 per cent., exclusive of that between the layer. Take it at only 2·67 per cent., and the amount will

correspond to *two quarts of water for every cubic foot of rock.* As a cubic inch of water at the ordinary atmospheric pressure will produce nearly a cubic foot of steam, the amount was large in proportion to the amount of rock, whatever the pressure; and this would be true if the proportion of water was half less. Under such circumstances at high temperatures, steam was at hand ready for work at chemical and other molecular changes. In general, the beds contained as stated above, all the ingredients needed for their transformation into crystalline rock.

But this water of the original sedimentary rocks may have been oceanic water, which is mineral water, of indefinite distribution, abounding in salts of soda and magnesia, and yielding also, in smaller proportions, boracic acid, and many other ingredients. The ocean made nearly all the sedimentary beds of the globe, and continued to penetrate them as long as they remained beneath the sea-level unchanged; and further, it has left in many of them great deposits of its sodium compound (common salt), with some of its magnesium and borax compounds; and briny waters are often given out when no solid salt is present. If the ocean contained more of phosphates in Archæan time than now (p. 593), or of any other ingredient, this also would have been among the contributions of its waters. With subaerial sedimentary beds, waters of mineral springs may have given some ingredient, whenever they had a chance; but these have taken a larger part in local metamorphism than in regional.

3. Effects of the heat and moisture. — Superheated steam is well-known to be an exceedingly powerful chemical agent as a destroyer of cohesion, a solvent, and a promoter of decompositions preparatory to recompositions.

Mr. J. Jeffrys, in 1840, subjected some feldspathic and other siliceous minerals to a current of steam inside of a kiln made for vitrifying brown stone ware, and with them a few articles of the stone ware. At a full red heat, little effect was produced; but above that of fused cast iron, there was rapid erosion, and in ten hours, "more than a hundred weight of mineral matter had been carried away in the vapors." Daubrée has experimented with the direct object of making silicates by means of superheated steam. Having put a little water in a strong glass tube, and after closing it, subjecting it to a temperature of 750° F. for several weeks, he obtained, besides a hydrated silicate allied to the zeolites, quartz in well-defined crystals, and, in another case, perfect crystals of the light-colored variety of pyroxene, called diopside. A clay, from near Cologne, used in making crucibles, heated in the glass tubes, became charged with scales of a mica or chlorite (the quantity being too small for an analysis). Crystals of

common feldspar, or orthoclase, occur in the cavities of some igneous rocks in the copper region of Lake Superior as a secondary product, and the accompanying facts make it certain that it was made by means of heated moisture. Quartz, feldspar, and mica, are the common minerals of several of the most abundant of metamorphic rocks; and pyroxene is a constituent of other kinds. Daubrée's important observations on the minerals made in various hot springs are mentioned beyond in connection with the remarks on the origin of veins.

The making of deposits of silica does not require high heat, as already explained on page 708. In addition to the facts there stated, it may be added that geodes of chalcedony and agate, eight to ten inches in diameter and of modern origin, come from Florida, that are the remains of hemispherical masses of coral, the exterior still showing the stars of coral, while the interior is a great agate-lined cavity; they were made by the siliceous waters of the warm springs of the region. J. Arthur Phillips found crystallized quartz and chalcedony among the recent deposits of Borax Lake, in Lake County, north of San Francisco, and at Steamboat Springs, in Nevada. Daubrée detected quartz in the form of chalcedony among the deposits of the hot waters of Plombières. It should be considered, further, that the quartz which makes the flint and chert of the world, and has silicified the fossils of many strata, was dissolved by cold waters; it was mostly in the opal state when dissolved, but was deposited in the state of quartz.

Thus the making of quartz, and quartz crystals, and the solidification of rocks by means of quartz, are easy effects in the presence of hot moisture; and the crystallizing of sedimentary beds into granite, gneiss, and mica schist, are other results which with its aid may be accomplished.

With superheated steam, at a high temperature, that plastic state, as experiment has shown, may be produced, which is like fusion from heat alone in its ability to obliterate all previous structural features, and which therefore would make a granite out of materials that otherwise would have the bedding of a gneiss; while with low heat, the bedding would be retained, as in the schistose metamorphic rocks.

With still lower temperature, solidification would be the only prominent result, or a change of color in the rock, or an expelling of a vaporizable ingredient, as in the case of mineral coal and carbonaceous schists.

With regard to limestone, the experiment of Hall, early in the century, showed that chalk, when heated in a closed tube, became crystalline calcite, with no loss of its carbonic acid. But as limestone (calcium carbonate) is decomposed by hot siliceous solutions, a stratum may lose part of its thickness in the process of metamorphism.

Different degrees of *moisture present* would naturally have determined different metamorphic results. Too dry a heat may have made crystalline limestones or quartzytes of *feeble cohesion*. An excess of moisture with a low grade of heat may have produced the *hydrous* rocks, chlorite schist, and hydromica schist; while with less moisture, hornblende schist and mica schist would have been formed; and, in fact, a stratum is sometimes chlorite schist in one part and hornblende schist in another, the constituents, excepting the water, being nearly the same.

Again, sedimentary beds that differ too little to the eye to have distinct names may make very different rocks through metamorphism. A shale is a shale whether it contain potash or not; but through metamorphism, it might make a mica schist if potash were present, and could not if potash were absent, but might then become hornblende schist. A stratum of mica schist often graduates into hornblende schist (as happens a dozen miles west of New Haven, Conn.); and because the mud-bed from which the rocks were made varied a little in its ingredients, as mud-beds do in existing oceans. A sandstone is a sandstone, even when containing much clay; but after metamorphism, it may be quartzyte in one case and a quartzose gneiss in another. Much or little oxyd of iron in a shale is little noticed, but in the metamorphosed shale it may lead to a whitish crystalline rock in one case, and a black in the other, with different mineral species giving the color.

In some cases the bedding of rocks has been obliterated by metamorphic action, without their reaching the condition of plasticity, in consequence of a tendency to promiscuous crystallization in the grains of the constituent minerals. This is true, for the most part, of those consisting of hornblende alone (hornblendyte), hornblende and a feldspar (dioryte, labradioryte), feldspar (felsyte), feldspar and quartz (granulyte or mica-less granite, quartz-felsyte), serpentine, and some others, as explained on page 627.

A bedded structure may also be obliterated by the soldering together of layers, when the rock is subjected to heavy pressure, and all evidence of it disappear, unless the layers differ in color or constitution; as has happened in the marble of Rutland, and in other cases, where a pure limestone is upturned at a high angle, — this position being evidence of its former subjection to heavy pressure.

The following table presents a general view of the composition of the more common rock-making materials, showing their close similarity. These species are briefly described on pages 52–58. The names mica and feldspar each include several species: —

Silica	Quartz.
Silica + magnesia and water	Talc.
Silica + magnesia and water	Serpentine.

Silica + magnesia + lime or protoxyd of iron	Pyroxene.
Silica + magnesia + lime or protoxyd of iron	Hornblende.
Silica + magnesia + alumina and protoxyd of iron	Chlorite.
Silica + alumina	Andalusite.
Silica + alumina	Cyanite.
Silica + alumina + fluorine	Topaz.
Silica + alumina + oxyds of iron	Staurolite.
Silica + alumina + potash + oxyds of iron, or magnesia	Mica.
Silica + alumina + lime and soda	Scapolite.
Silica + alumina + lime, magnesia, iron, or manganese	Garnet.
Silcia + alumina + oxyd of iron	Epidote.
Silica + alumina + potash, soda, or lime	Feldspar.
Silica + alumina + alkali, magnesia, and boracic acid	Tourmaline.

The presence of phosphoric acid, from organic remains, has often determined the formation in metamorphic limestones, and even sometimes in granite and other metamorphic rocks, of crystals of *apatite* (phosphate of lime); and the presence of fluorine may have led to the crystallization of *chondrodite*, *topaz*, and some other species.

4. Origin of the Heat causing Metamorphism.

Rocks, during the process of metamorphism, are undergoing extensive displacements and foldings, profound fracturings and faultings, if not also crushings, in some parts — as illustrated in the examples which have been described on page 213. Metamorphic rocks are always displaced and folded rocks, and seldom for any considerable distance horizontal. Where the foldings are most numerous and abrupt, reducing the strata to a system of parallel dips, by the pressing of fold upon fold, there the metamorphism is most complete. Now, the heat caused within the rocks by the friction, and whatever crushing may have taken place, if not sufficient to produce fusion and volcanoes, as Mallet has claimed (p. 719), may be sufficient for the feebler work of metamorphism; and if so, it is then true, as Wurtz was first to announce, that the heat of metamorphism was made in the very rocks that were altered by the movements to which they were subjected. But this is not the source of all the heat; for the deposits undergoing simultaneous metamorphism have often had great depth — even several miles, in some cases, — and, as stated on page 718, heat from the earth's interior has risen into the pile of beds as fast as accumulation went on above, and an important addition to the heat for the metamorphism may have thus been derived. Scrope and Babbage, who were the first to appeal to this as the source of heat, regarded it as alone sufficient; and, accordingly, a very great thickness of overlying deposits was thought necessary to produce the effects. Hence, it happened that such rocks as gneiss, granite, and the like, have been called *Hypogene* rocks, meaning *rocks made at great depths*. But there is no evidence, in many cases, of so great thickness as the theory demands; and, again, a thickness of 10,000 to 15,000 feet in sedimentary beds has been observed — as in the Nova Scotia coal formation

— without marked metamorphism below. Professor Geikie remarks that in the South Wales coal-field the Carboniferous limestone, although covered by other rocks to a depth of 10,000 to 12,000 feet, is unaltered, while the rocks of the Central Highlands of Scotland are intensely altered, though they were not at the time of metamorphism covered by more than 5,000 feet of strata.

5. Local Metamorphism.

Local metamorphism has often occurred in the walls or vicinity of dikes of eruptive rocks, and in regions of hot springs. For example: "Crystallizations of epidote, tourmaline, garnet, chlorite, quartz, hematite and magnetite, besides various zeolites, occur in the Triassico-Jurassic red sandstone of the Atlantic border of North America, in the vicinity of the trap-dikes which intersect it, that were produced through the agency of the heat the trap had when ejected. The garnets occur at Mill Rock, New Haven, Conn., in the sandstone within a few yards of the trap, and also in rifts in the trap near its walls; and those in the latter are yellow topazolites of great beauty, though small. At Rocky Hill, N. J., according to H. D. Rogers, the "baking" effects of a trap-dike are distinct for a fourth of a mile from the dike; and, fifty feet off, a thin bed contains "kernels of pure epidote," and cavities that are "studded with crystals of tourmaline." At one place the latter crystals are half an inch in diameter.

The sandstone, where containing these minerals, has generally lost its usual red color, and become grayish-white to greenish, the green color coming from the chlorite generated by the heat. The same trap dikes also intersect chlorite slate to the west of New Haven, Conn., and here the rock is changed from a dull green to black, owing to the production of some magnetite, in accordance with the common blow-pipe result when an iron-bearing silicate is heated.

A trap dike intersecting the clayey layers, sandstones, and coal-beds of the island of Nobby, New South Wales, has baked the clayey layers to a flint-like rock (as described in the author's Expl. Exped. Report), to a distance of two hundred yards from the dike, the whole length of the island; the baking effect must have continued much farther.

Baking effects, and sometimes crystallizations, have been occasioned by the *burning of coal-beds.*

Mr. J. A. Allen states that the burning of the coal-beds of the Lignitic Tertiary of Dakota and Montana — how ignited is not known — has changed clays to hard and sometimes porcelain-like rocks, usually reddening them, and also to beds of a half-fused cellular or scoriaceous and pumice-like character, looking like the products of a volcano. One of the regions thus burnt over, on the Little Missouri, is twenty to thirty miles broad by two hundred miles in length. Others occur in the Yellowstone at the mouth of Powder River, and along the latter stream; about the sources of Tongue River, within a few miles of the Big Horn Mountains, and on the north fork of the Cheyenne River, as observed by Hayden. Fragments of pumice have been found on the Missouri as far south as Fort Pierre, and the early explorers supposed them to be the

products of unknown volcanoes, high up in the mountains. The baked rocks, besides giving their red tints to the country, resist erosion, as Mr. Allen states, and so protect the hills from denudation, and become prominent features of the region.

The production of the metamorphic results by the heat of erupted rocks, and the extent of the region affected, has depended chiefly on the presence of moisture for conveying and utilizing the heat. Near New Haven, Conn., the sandstone walls of a dike crumble in some places into small chips, apparently because of the want of moisture there at the time of the eruption, and in others, the rock, although a coarse conglomerate, is very firmly consolidated. The presence of steam is often indicated by remains of the tubular channels through which it rushed, their walls bleached and penetrated with chlorite; and the chlorite, in some places near by, is fibrous in structure and spangled with minute but perfect crystals of hematite.

A region invaded by trap eruptions is often also, as a consequent or concurrent fact, a region of steaming fissures and of hot springs, conveying the heated moisture widely through the strata of the region; and thus the sand-beds of the same Mesozoic formations in the Connecticut Valley were generally *reddened* as well as consolidated — oxydation of iron, when taking place through the agency of hot waters, producing the anhydrous sesquioxyd of iron or the red oxyd.

These examples of alteration illustrate not only local, but also regional metamorphism, for the minerals formed are among those that figure extensively in metamorphic rocks. Chlorite, garnet, tourmaline, are among the most common of such minerals; and if these and other species can be made under the rather rapid and coarse conditions afforded by the eruption of an igneous rock, much more complete should be the results of slow-working metamorphism. It is observed, also, that these minerals are made by selecting and combining the needed elements; it is not mere crystallization. The iron of the epidote, chlorite, garnet, tourmaline, must be the iron that gives the red color almost everywhere else to the sandstone. The tourmaline crystals seem to show that marine waters (or, perhaps, borate springs, made earlier from the ocean's waters) supplied the boracic acid needed in their constitution. The hematite crystals (Fe_2O_3) were probably derived from the oxydation of the magnetite grains (Fe_3O_4) of the sand-beds. The quartz crystals were made out of silica taken from the siliceous minerals (feldspar, etc.) that were decomposed by the steam to furnish material for the new crystallizations; and the heat, as far as it reached through the sand-beds, even if of low degree, made in the same way the siliceous solutions that produced the consolidation of the sand-beds.

6. Chronological Relations of Metamorphic Rocks.

It is generally admitted that metamorphic rocks are not of any particular geological age. But it is still queried whether particular kinds do not characterize periods or ages.

Some peculiarities of Archæan formations are stated on page 152, namely, their comprising beds of crystalline hematite, and magnetite that are often twenty-five to over a hundred feet thick; and showing the unusual amount of iron of the era also in the wide distribution of hornblende-bearing rocks, such as syenyte and syenytic gneiss. Besides, metamorphic rocks containing corundum, chrysolite, and zircon are far more common among the older Archæan terranes than in subsequent formations. The older Archæan gneisses, which also are widely distributed, are usually thick-bedded and much jointed; and the bedding is often faint and obscured by the joints; yet in other cases the bedding is brought out with bold contrasts of color between the black hornblende beds or mica layers and the whitish feldspathic. Coarsely crystallized Labradorite rocks, such as noryte, are also a feature of some of the older Archæan regions, — rocks that have the same composition as the dolerytes among igneous kinds. But thin fissile mica schists and evenly schistose and easily-cleaving gneisses are not common.

Thus there are some characters that occasionally give aid in the determination of the Archæan age of a metamorphic rock. But, in general, Archæan gneisses and granites cannot be distinguished from those of later time; and there are Archæan quartzytes, diorytes, hornblende schists, chlorite schists, which are identical in all respects with others of subsequent origin. This is what should be expected, since the Archæan rocks are the chief source of material for the later rocks. Their trituration produced sediments; metamorphism of the sediments reproduced the crystalline rocks. There has never been a year since the first granite and gneiss began to exist, in which great beds of quartz-sand were not in progress, through weathering and erosion, as great of granitic sands (that is, sands consisting of feldspar and quartz, with more or less mica), and greater beds of mud; and the mud direct from such a source would largely have been made of triturated or granulated, instead of decomposed, feldspar. Daubrée has shown that the trituration of feldspar by the ocean's waters removes but a bare trace of the alkalies, — far less than when the trituration is done by fresh waters.

As these older Archæan rocks are various in their distribution, so the different kinds of sediments originated from them would be as various; and it is impossible that the same kind should at any one time

have been formed all over the globe, so as to characterize an age. And as Archæan hills and mountains have continued to exist until now, sediments of the same kind may have been made over and over again until now, through all geological ages. A particular kind of metamorphic rock should therefore not be confined to a particular area or age. In regions like Scandinavia, Scotland, Labrador, Canada, New England, and others similar, the original older Archæan beds still exist; and the succeeding metamorphic rocks are their direct descendants; and the chief difference which appears is a somewhat greater preponderance of quartzose and micaceous rocks. *Even as late as the Triassic and Jurassic eras*, the sediments laid down along the Connecticut valley, and in New Jersey, have the feldspar in most parts in as great abundance and in as pure and unaltered a state as the granites of earlier time; and subjection to the metamorphic process would have made of much of it granite like the older, except that the mica would not in all parts be in sufficient proportion.

Again, similar metamorphic gneiss, mica schists, chloritic and hornblendic rocks, are proved by fossils to have been made in different periods. The limestone region of the Green Mountains shown by fossils to be Lower Silurian (p. 183), contains, in conformable beds with the limestones, quartzyte, hydromica, chlorite and mica schists, and various gneisses; and the Upper Silurian region of Bernardston, Mass., and Vernon, Vt., comprises conformable beds of quartzyte, mica schist, various massive and schistose hornblende rocks, and quartzose gneisses and syenyte, conformable with a Helderberg Crinoidal limestone. Serpentine and mica schists occur of Triassic age, as shown by J. D. Whitney, in the Sierra Nevada, and of Cretaceous age in the Coast Range of California. So at Rothau, France, the rock containing the *Calamopora spongites* is a hornblende rock, containing epidote and garnets.

The repeated trituration of sediments ultimately causes the leaching out of the alkalies of the feldspars. Hence, the shales of regions *remote* from crystalline rocks generally contain little alkali; and, when this is the fact, the metamorphic process would not convert them into mica schist or gneiss. The tendency to this leaching effect, with increasing remoteness from the region whence the material of the rock came, is illustrated in mica schist a few miles west of New Haven, Conn.; where, as stated on p. 761, the schist changes on going southward gradually to a hornblende schist, — hornblende, unlike the mica (here biotite), containing no potash.

Pseudomorphism. — A Pseudomorph is a crystal that has a form that does not belong to the material constituting it. If a crystal has the form of calcite, but is really quartz in composition, it is a pseudomorph; it was once calcite, but in some way, probably

through the action of siliceous waters, has been changed to quartz. Silicified shells and woods are also examples of pseudomorphs. The chemical methods of making pseudomorphs are very various, and some of the processes are the same in kind with those that have operated on a larger scale in metamorphism. For example, the several minerals, chrysolite, pyroxene, chondrodite, chlorite, which are all anhydrous magnesian silicates, and others, have been changed to the *hydrous* magnesian silicate, serpentine; for serpentine occurs with the crystalline form of each of these species, and some of the pseudomorphs observed contain a portion of the original mineral at the centre. Such serpentine pseudomorphs are very common and various, and this is one reason for doubting the organic nature of *Eozoön* (p. 158). As another example, the mineral corundum (crystallized alumina) has been shown by Genth to occur, in western North Carolina, changed, through some way or other, to chlorite, margarite (a kind of mica), cyanite, diaspore, and other mineral species. So pyroxene has been proved to occur altered to talc, the rensselaerite of Fowler, Dekalb, and other places in northern New York, having in some places the composition of talc, with the cleavage planes of pyroxene. Again, large hexagonal prisms occur at Diana, in Lewis County, N. Y., which consist of the soft hydrous silicate called pinite (resembling the agalmatolite of China, there worked into images and ornaments) which were derived, it is supposed, from the alteration of nephelite (a silicate related in composition to the feldspars). This making of silicates, if only in an isolated way, shows what nature's out-door processes are capable of doing. But these same methods of chemical change have sometimes gone forward on an extensive scale sufficient to make rock formations, so as to be true examples of

Pseudomorphic Metamorphism. — Chrysolite has been changed to serpentine so extensively as to make large beds of it; and so has pyroxene, and perhaps also chondrodite. Distinct altered crystals often occur in such beds, and confirm other evidence as to the origin of the great masses.

In the rock of the Alps named Euphotide (p. 75), the prominent constituent, called saussurite, in some places shows, by the forms of crystals, that it is altered labradorite; its granular texture and other characters prove it to be throughout of this general nature, — an altered feldspar. In some regions portions of the mass are still true labradorite. Along with the saussurite occurs the hornblende mineral smaragdite, and this is proved to be in some places pseudomorphous pyroxene. Serpentine in beds often accompanies the rock, and this sometimes indicates that it may have come from the alteration of pyroxene. Euphotide is thus an example of pseudomorphic metamorphism. It received a crystalline condition first through ordinary metamorphism, making it a labradorite and pyroxene rock, or labradorite and hornblende rock; but now in consequence of a subsequent change, it is euphotide. (On this subject, see Amer. J. Sci., III., xvi., 340, 1878)

Much of the doleryte of the world, as microscopic examinations by various observers has shown, is chloritic, through the change of much of the pyroxene, with sometimes part of the feldspar (labradorite), to a hydrous silicate of the chlorite group. The forms of pyroxene and labradorite are still more or less distinct, or can be made out through gradations in a series of specimens; but now chlorite constitutes the crystals, or parts of them. Here again is pseudomorphic metamorphism. Other results of the metamorphic change often exist in the chloritic doleryte which are here passed by without notice.

With regard to the doleryte, it has been stated, on page 748, that the water which produced the change (often making the doleryte also amygdaloidal as well as dull in lustre), must have been received into the rock while it was melted and on the way to the surface, and came from subterranean sources among the intercepted strata; for the distance to which moisture can "descend into such rocks from above after they are solid and cold" is very small, as is shown by the limited depth to which decomposition goes on; and the inability of this cold water to make chlorite out of pyroxene, is proved by its uniformly oxydizing the iron, if air is present, and by the absence of action if it is not. Analogous changes have taken place in trachyte and phonolyte, filling them with zeolites, and in porphyries, hydrating and making quartz-crystals in them. This view

is sustained by Daubrée's remark respecting the clay-porphyry of Germany containing quartz crystals and kaolinized feldspar crystals, that "the change must have been produced before the rock was completely cooled."

In these cases, the igneous rock at first was so far consolidated that its minerals took their crystalline condition, and afterward came the change. It follows, thence, that the moisture could not make these hydrous silicates out of the material present, while the temperature of fusion existed, but only after cooling was partly completed. It is so in the lavas of a volcano; although moisture is so abundant as to furnish vapors freely from the vent, it causes no changes on passing through the lavas. In fact, these hydrous minerals lose their water, or most of it, below the temperature of ignition, and it is natural that they should require, notwithstanding the pressure, a comparatively low temperature. Confinement with the minerals for a long period during the slow cooling seems to be the condition under which the metamorphism and the attendant making of zeolites, agates, etc., takes place.

In the making of chlorite schist by metamorphism, the moisture was present in the sediments, and was retained in consequence of the pressure, and the low degree of temperature under which metamorphism took place, so that the case is different from that of chloritic doleryte.

As to the euphotide, the conditions, even if similar, were in some important respects different. The rock, as originally made, had the chemical constitution of true doleryte, and if pyroxene was present in it mainly, instead of hornblende, it had its mineral constitution. But the labradorite in doleryte has not been found changed to saussurite, while it is so over great areas in euphotide.

Dolomization. — The making of dolomite out of limestone materials was, according to Von Buch's theory, a process of metamorphism; for it attributed the change to the action on existing limestones of magnesian vapors attending the eruption of augitic igneous rocks. But such an effect, if taking place, would necessarily be local; and magnesian vapors are not thus generated. Magnesian limestones are, in fact, some of the most extended of rock formations, and constitute a considerable part of the *uncrystalline* limestones of the world. Moreover, they bear evidence that they have become magnesian, for the most part, in the process of their formation, and not through subsequent change, and the crystalline variety (as that of the Green Mountain region from Vermont to New York) is only a metamorphic rock of this nature. That this is so, may be inferred (1) from the extent of such limestones; (2) from their usual compactness, which would not be so common if they were a result of chemical alteration (since magnesium has much greater density and less atomic weight than calcium, and, therefore, a limestone is diminished much in bulk by the change to dolomite — the diminution being about one eighth); and (3) from the fact, announced in the author's Exploring Expedition Geological Report (1849), that a white, compact coral limestone from the reef-rock of the elevated coral island. Metia, north of Tahiti, has nearly the composition of true dolomite, as determined in an analysis by B. Silliman (the analysis obtaining, from 100 parts, 61·93 of calcium carbonate and 38·07 magnesium carbonate). Further, the texture of the ordinary magnesian limestones usually indicates that they are not simply of chemical origin, for it is quite unlike that of travertine and any purely chemical calcareous deposit.

The general character of the Metia reef-rock, its fineness of grain and compactness, and its position, led to the inference that it had been formed from the coral mud that had been deposited in the shallowing lagoon of the small coral island. The occurrence of such mud is common under these circumstances, and not unfrequently beds of gypsum are formed in it, as stated on page 235. Since reef-forming corals contain very little magnesia (page 60), the facts seemed to sustain the inference (as stated in the report referred to) that the coral mud became magnesian though the magnesian salts of the ocean (the chloride chiefly, or both the chloride and sulphate), at the time of its solidification, and without the aid of heat — slow action through centuries accomplishing what is not possible by quicker methods. In such a shallowing lagoon, holding concentrated sea-water, the conditions might be favorable for the action, although without

the concentration it would not take place; and hence variations in such concentration may account for the differences in composition that occur between the successive layers of some magnesian limestones, or, the alternation of magnesian and non-magnesian layers, or the occurrence of dolomitic fossils when the rock is purely calcareous; fossils, as numerous facts show, being the first part to become changed.

According to one of the methods of forming dolomite, suggested by T. S. Hunt, calcium bicarbonate and magnesium sulphate in solution, react on one another, and in the double decomposition produce magnesium bicarbonate and calcium sulphate (gypsum), and then, on evaporation, a deposit of the gypsum takes place, and if the supply of the calcium bicarbonate continues, "the two carbonates fall in a state of intermixture." But it is not yet shown that dolomite thus results; and the theory does not meet the case of the Metia coral-reef rock, since this was not a chemical precipitate, but, like other great limestones, it was of organic origin.

Besides dolomite, originating in the manner above mentioned, there is other dolomite which is a result of the chemical alteration of beds of true limestone. Adolf Schmidt has pointed out (Trans. St. Louis Acad., 1875) that, at the large lead and zinc deposits in the Subcarboniferous limestone of Missouri, the limestone has been rendered dolomitic along fissures and about the ores; and he refers this dolomization — following Bischof — to the action of "solutions of magnesium bicarbonate." Limestones have been found to have in many regions transverse bands of dolomite crossing the bedding along the courses of joints or fractures; and the formation of the dolomite has been attributed to the action of solutions of magnesium carbonate by some, but to the magnesium salts of sea-water by Prof. Harkness, who describes some examples in the Carboniferous limestones of Ireland. Crystals of calcite altered to dolomite, have been described by various authors.

In a memoir on the famous dolomite region of the Tyrol, Dölter and Hörnes, geologists of Vienna, discuss this subject at length, and reach the following conclusions: (1) Some large limestones, weakly dolomitic, may have been made out of those organic secretions which contain a little magnesia; (2) minor cases of the production of dolomite are due to the alteration of limestone through the introduction of magnesium carbonate; but (3) the larger part of dolomite formations, whether more or less rich in magnesia, have been formed from organic calcareous secretions through the action of the magnesium salts of sea-water, especially the chloride.

The following are titles of some works and memoirs bearing on the subject of metamorphism: —

G. Bischof: Lehrbuch der Chemischen und Physikalischen Geologie; 3 vols. 8vo, 2d ed., Bonn, 1863–1866.

J. Roth: Allgemeine und Chemische Geologie: 1st vol. on the Formation and Alteration of Minerals and on mineral and marine waters, 8vo, Berlin, 1879; a full and systematic exposition of the known facts.

C. Lyell: Principles of Geology, 1st ed., 1833, London. First use of the term *metamorphic rocks;* also first application of the term *hypogene rocks* to granite, gneiss, and other crystalline kinds, supposed to be *nether-formed* rocks.

S. P. Scrope: See page 748.

C. Babbage: See page 722.

Scheerer: Aqueo-igneous Origin of Granite, etc. Pogg. Ann., lxviii., 319, 1846. Bull. Soc. Geol., France, II., iv., 408, 1847. Ninth Bridgewater Treatise (1851), 225.

H. C. Sorby: Microscopical Structure of Crystals, indicating the origin of minerals and rocks, Quart. J. Geol. Soc., xiv., 453, 1858, and Reports Brit. Assoc., 1856, p. 78; 1857, p. 92; shows, by careful experiments, that microscopic cavities in crystals deposited from solutions in water, contain water; that the size of the vacuities in cavities depends on the temperature and pressure; that those in crystals formed from igneous fusion contain glass or stone; that those in crystals made under great pressure, by the combined action of igneous fusion and water, or by igneo-aqueous fusion, may contain either water alone, or glass or stone; and thence deduces, among other results, that the

quartz and granite veins and ore were not from igneous fusion; that water was concerned in metamorphism as well as vein-making; that minerals of various volcanic rocks often contain glass cavities, and also gas or vapor cavities; that some basalts and other igneous rocks have been as much metamorphosed by water as some sedimentary rocks by heat; and gives calculated results as to the pressure under which cavities were made, and thence, less reliable conclusions as to the thickness of the overlying rocks. — The Structure and Origin of Limestones, in his Presidential Address before the Geological Society, in 1879, Quart. J. Geol. Soc., xxxv., 65, 1879.

A. Delesse: Études sur le Métamorphisme des Roches, Annales des Mines, V., xii., 89, 417, 795; xiii., 1857; produced as a separate volume, in 1861, 4to, and 1869, 8vo; attributes metamorphism to those agencies which, "as remarked by Élie de Beaumont, are encountered beneath the earth's surface, that is, heat, water, pressure, and molecular action," and plasticity to heat and moisture combined. Sur l'Origine des Roches, etc., Bull. Soc. Geol. de France, II., xv., 728, 1858, and as a separate volume, 1858. Recherches sur les Pseudomorphoses, Annales des Mines, xvi., 1859.

A. Daubrée: Études et Expériences Synthétiques sur le Metamorphisme, Comptes Rendus, 1860. — Expériences Synthétiques Rélatives aux Météorites, Comptes Rendus, lxii., 1866. — Études Synthétiques de Géologie Expérimentale, 1ère Partie, Application de la Méthode Expérimentale à l'Études de divers Phenomènes Géologiques, 8vo, Paris, 1879. These works are made up largely of the results of original research.

J. Jeffreys: Decomposing action of Steam, Rep. Brit. Assoc., 125, 1840, and Amer. J. Sci., xlviii., 397, 1845.

R. Tilghman: On the decomposing Power of Water at high Temperatures. Amer. J. Sci., II., v., 266, vi., 260, 1848.

T. S. Hunt: Origin of Crystalline Rocks, in an Address before the American Association in 1871. (See also for criticisms of the views in the address, Amer. J. Sci., III. iii., 86, iv., 41, 97, 1872, and ix., 102, 1875, and Proc. Boston Soc. Nat. Hist., xviii., 200, Nov., 1875.) On some points in Chemical Geology, Quart. J. Geol. Soc., Nov., 1859, and Canadian Naturalist, Dec., 1859. Granites and Granitic veinstones, Amer. J. Sci., III., i., and iii., 1871, 1872. On the Reaction of the Salts of Lime and Magnesia, or on Limestones, Dolomites, and Gypsums, Amer. J. Sci., II., xxviii., 160, 365. See, also, his "Chemical and Geological Essays."

J. D. Dana: On the Rocks of the Limestone Region of the Green Mountains, including the Taconic schists in the central and western portion of the region, Amer. J. Sci., III., v., vi., 1873; xiii., xiv., 1877; xvii., 1879. — On the Helderberg Formation of Bernardston, Mass., and Vernon, Vt., ibid., xiv., 379. 1877. — On Serpentine Pseudomorphs and other kinds from the Tilly Foster Iron Mine, Putnam Co., N. Y., ibid., viii., 371. 1874. Dolomization, Geol. Rep. Wilkes' Expl Exp., 1849, 153, 731, and Amer. J. Sci., vi., 269, 1848. Corals and Coral Islands, p. 357.

Henry Wurtz: Metamorphism due to heat of friction, Amer. Journal of Mining, Jan. 1868, and Amer. J. Sci., iii., v., 385.

F. A. Genth: Corundum (of North Carolina), its Alterations and Associated Minerals, Proc. Amer. Phil. Soc., Philadelphia, 1873.

5. MINERAL VEINS, LODES, LOCAL ORE-DEPOSITS.

Veins in rocks have been described, on page 108, as the fillings of cracks or fissures, and they are there divided into (1) *dikes*, or those that have been filled by an eruption of melted rock, and (2) *true veins*, those that have been filled by other methods. The distinction is an important one, but is not always easy of application.

1. **Positions.** — Fissures, and thereby veins, may be confined to single beds of rock, or single strata, one bed or stratum being variously

intersected by them, while the next below or above has none. But, also, they may descend through many strata to great and unexplorable depths.

They may cross the planes of bedding at all angles, and in several directions. But, in general, those in a region that were made together are (1) nearly parallel, but occasionally cross, often at right angles; and (2) are generally similar in material.

Veins may cut transversely to the bedding, or be parallel with it. In schistose or slaty rocks, if the beds stand at a high angle of dip, the veins often follow for long distances the course of the bedding, because a rupturing force that tends to make fissures in the direction of the bedding more easily produces separations or openings between them than fractures across them — planes in the direction of the bedding being those of weakest cohesion; or there may be an interrupted series of such openings, those of the series made severally between different layers. Some of the largest of granite veins are of this kind, that is, they are conformable for considerable distances to the bedding. Those of Middletown and Portland, Conn., are examples. Such veins often include thin or thick layers or portions of the schistose rock, or may be banded by it.

Further, in the flexures of a thin-schistose or slaty rock, the laminæ very commonly become separated, as the leaves of a quire of paper separate on bending it, and thus innumerable thin spaces are made between the leaves, sometimes many to an inch, which subsequently may become filled with quartz or other mineral matter, so that the rock is delicately seamed with veins parallel with the bedding, sometimes looking like a fine white ruling. But the same slaty rocks often contain, in other places, large and irregular veins with abrupt expansions and contractions, owing to irregularities in the breakings.

In the language of miners, veins containing ores are called *lodes;* the material inclosing the ore is called the *gangue;* and the rock outside of the vein is the *country-rock.*

2. **Forms.** — The forms of veins are exceedingly various. Some of them are illustrated in Figures 116 to 119, and 132, 133, on pages 109–112, to which the reader should here turn. They may have (1) parallel walls, or (2) contract and expand irregularly along their course. The latter is the most common condition, but the two may characterize different parts of the same vein. They may (3) make a network through the mass of the rock, so that, if metalliferous, the whole rock is removed to obtain the ore.

(4.) When large chambers and passages in a rock contain ores, the fillings are often spoken of as veins, even when there is no evidence that the chambers are connected with, or originated in, fractures.

The forms of veins and their courses are greatly varied by *faults*. Some examples are represented in figures on pages 109 and 111, and these figures may be taken either as of natural size or as representing faulted veins a thousand times as large. But faults may divide veins not merely into parts that are little displaced, but into portions that are shoved hundreds or thousands of feet to one side or the other, above or below, to the immense perplexity of the miner. Even

Fig. 1128.

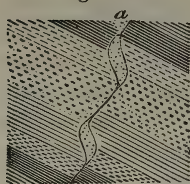


Fig. 1129.

small faultings may divide a vein into isolated portions that have no apparent connection whatever. The annexed figures illustrate one method; the fissure being sinuous, a slight movement in the direction of the vein has brought the projecting part of the two sides together, and doubled the width of the rest. In Fig. 1129, from De la Beche, representing nature most correctly, *a* is the line of a somewhat sinuous fissure, *b*, the result of a fault to the right along this line, and *c*, the result of a fault to the left. In rocks that are nearly vertical in dip, the subdivisions of the vein made by faulting may be vertical, as is illustrated by each of the above figures, if it be regarded as representing a horizontal surface.

In the case of faulted veins, the inclination of the plane of the fault to a vertical plane is called by miners its *hade;* and it is so common to find the hade or pitch toward the *down-throw* side, that when it is not so the fault is called a *reversed fault.* The down-throw is usually on the same side (referred to the points of the compass) in all the veins of a region, as if all had been produced by the same subterranean movement.

In the making of fissures, portions have often been separated from the walls; such a mass in a vein is called by miners a *horse*, while many of them may make it a *brecciated* vein. In some cases beds of rock have been crushed into large and small fragments for a great width; and the vein-material has filled up the spaces between them, so that the whole looks like an enormously coarse breccia.

3. Structure. — Veins (1) may be *simple* in structure, that is, have the material, not divided into layers, but as one mass from side to side, with the ore or metal, if they contain any, disseminated through the mass; or, (2) they may be *banded*, that is, have the materials ar-

ranged in layers parallel to the walls. Banded veins are much the less common kind. Frequently, only the broad parts or enlargements of a vein are banded and metalliferous. A banded vein of the simplest kind consists of a band of ore and one band either side of rock-material. But there are at times several bands of each. These bands may be alike on the opposite sides of the middle, except reversed in order, with variations, but chiefly in thickness; or they may be wholly unlike; and they sometimes indicate that the vein is in places or wholly a combination of two or more veins. In Fig. 1130, representing a portion of a Cornwall vein, near Reduth (from De la

Fig. 1130.

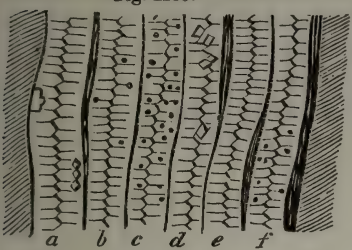
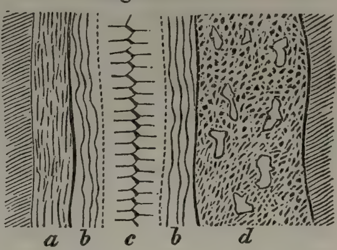


Fig. 1131.



Sections of Cornwall Veins.

Beche), the vein is made up of *six* quartz veins, each crystallized, and bearing, with one exception, some other mineral along the centre; *a* and *d* containing some fluorite; *b* and *f* a little, and *c* much, chalcopyrite, or copper pyrites. Fig. 1131 represents a section of another Cornwall lode, at Godolphin Bridge; it consists of either two or three veins side by side: *a*, consisting of quartz; *b c b*, made up of agate in bands along the sides and quartz at the centre; and *d*, a band of chalcopyrite or copper pyrites. Again, in Fig. 133, on page 112, there are three combined veins: *d d*, one; C, a second, consisting of ore; and *a bb c*, a third.

The rock-material of the vein may be granite, syenyte, or some related kind of rock, or it may be quartz, or spars. The most common of the spars in veins are calcite, barite (heavy spar or barium sulphate), and fluorite (fluor spar, calcium fluoride). The band of ore may be an even, continuous one; but the ore is oftener involved in the spars or quartz, occurring in large masses at one place, and only in threads or in scattered grains or crystals, or absent wholly, in another. Wide openings often occur along the centre of a vein, containing one or many minerals together.

True veins, as those of granite, quartz, or other material, which intersect the rocks deeply, have never a transversely columnar structure as a result of contraction or cooling, and in this respect are unlike

dikes of igneous rock. The fact indicates for the granite-like veins, that they are the fillings of fissures in hot rocks, while a period of metamorphism was in progress, and not in cold rocks like trap; and, for any others to which this last statement does not apply, that they are fillings made by gradual deposition, and not by injection in a state of fusion.

4. Origin of the Fissures. — (1.) When the veins are confined to a single bed (or are *gash-veins*), the fissures or cracks are usually due to contraction, either from drying or from cooling. The purer or more even-grained massive rocks, crack cross-wise, when the laminated beds which intervene do not — the former contracting as a whole and in any direction, but the latter mostly vertically. In the section of a nearly black semi-crystalline, highly tilted limestone, near Husted, Dutchess County, N. Y., the even-grained layers, two to four feet thick, are transversely gashed, and the cracks which narrow toward either surface, are filled in with calcite, making white veins, while the less pure laminated layers between are solid.

(2.) Fissures for the deeper veins have been made by subterranean action or movements; and their walls often bear evidence of the movements in the smoothing, or polishing, and grooving of the surfaces (making *slickensides*, in miners' language) from mutual abrasion. These fissures, even the largest, are not often continuous openings for miles, but rather series of fissures along a common direction. This feature is illustrated in the cut on page 19. Often, as there represented, two or more parallel ranges exist with the successive parts overlapping, and these parts may make an advancing or receding series; and transverse fissures may be of cotemporaneous formation. (On the origin of fissures see beyond.) The above points are well exhibited in the map (from Percival) on page 20, representing the Mesozoic trap-dikes of the Connecticut valley, a careful study of which is here recommended. Each line of trap on the map corresponds to a fissure; and the interruption and overlapping of the fissures in a series are finely illustrated.

(3.) Many of the faults in veins were made at the time *when the fissures were opened*, shovings having accompanied the fracturing; so that even the faulting of intersecting veins is not alone evidence of difference in time of formation; and those that were not made simultaneously may have been made with but a short interval between, within the same epoch of disturbance.

(4.) Veins are most common in metamorphic rocks, because a time of metamorphism is one also of disturbance and upturning. But periods of great fracturings have not always been times of metamorphism, and those of deepest fractures occurred in the Tertiary era. So

veins, some of them the richest in ores, intersect non-metamorphic rocks, and many are of Tertiary age.

5. Filling of Fissures; Making Veins. — Fissures have been filled, either (1) gradually, without eruptive aid; (2) abruptly, by means of plastic rock during a time of metamorphism; or, (3) through the agency of igneous eruptions. The first are *veins of infiltration;* the second, *dike-like veins;* the third, *contact-veins.*

1. *Gradually-formed Veins, or Veins of Infiltration or Segregation.* — Whenever a fissure is opened in a rock to a great depth the space thus made is almost like a vacuum as to pressure, compared with the region along side. Consequently, any materials in the adjacent rock that are vaporizable, under the new conditions, or can be taken up by heated moisture present, or by other solvents, will rush toward the opened space. Thus depositions against the walls will be commenced; and new supplies may be kept up until the opened space is filled or the supply gives out. The different materials may come from different levels in the walls of the fissures, especially when they descend to depths of high temperature; and these materials may be deposited at various heights along the walls above, according to the temperature and other conditions which their deposition may require. The material filling the fissure may hence come from the country-rock adjoining the part in which it is deposited; or from depths much below it; but not, it is believed, from areas of fused rocks or ores at the lower extremity of the fissure, as in making dikes.

In this way granite and quartz veins, ore-bearing or not, have been made; and the process has been carried forward most extensively in times, as just stated, of metamorphism, since these were times also of fracturings of the rocks, and of that temperature within them which is required both for metamorphism and for vein-making.

In the case of the larger granite veins, the temperature of the rocks and superheated steam was probably somewhere between 1,000° F. and 1,500° F., — high enough, and the action slow enough, to form, as constituents of the vein, in some cases, single masses of crystallized feldspar and quartz weighing tons; crystals of mica a yard across, and of beryl as large as a flour-barrel, besides making smaller crystallizations of rare columbates, tantalates, and other mineral species; and the enclosing rocks were changed at the time to gneiss, coarse mica schists, or others equally crystalline. With less heat, hardly enough for taking up feldspar material, the moisture within the rock became simply siliceous, and hence made quartz veins; and the rocks metamorphosed under the lower degree of heat, and containing the quartz veins, are mostly those that bear evidence of the less heat in their texture, such as fine-grained mica schist, hydromica schist, chlorite schist, argillyte, and semi-crystalline limestones.

Under this process of infiltration the vein-material becomes firmly adherent to the walls, and sometimes graduates into them; and the country rock is sometimes penetrated, more or less deeply, with crystallizations of some of the vein-materials.

When quartz and granite veins cross one another, the former are the younger; and they were formed either in a later part of the epoch in which the granite was made, when the heat had diminished, or at some subsequent epoch.

It is remarkable that quartz veins are far oftener metalliferous than granite veins. Nearly all gold-bearing veins are of quartz; and the same vein may contain also ores of lead, zinc, copper, and other metals, besides the universal pyrite. The veins of copper ore in metamorphic regions are usually quartz veins containing chalcopyrite (or copper-pyrites). Tin ore (cassiterite, or oxyd of tin), besides occurring frequently in granite veins, is common in quartz, but it is often a micaceous quartz, showing a higher temperature for its origin than is needed for ordinary quartz veins, and indicating this also in being often accompanied by crystals of topaz, tourmaline (schorl), ores of tungsten (wolfram, especially), and other minerals.

(2.) The ore-veins and *local ore-deposits* of *non-metamorphic* regions, which occur in limestone formations, are among the most remarkable. They include some of the largest lead mines of the world, as those in the Subcarboniferous limestone of the Cumberland and Derbyshire regions in England, in the Devonian (Eifel) limestones of Westphalia, in the Triassic (Muschelkalk) of Upper Silesia, the Trenton (Galena) limestone of Wisconsin and northern Illinois, the Calciferous (Lower magnesian) and Subcarboniferous limestones of Missouri; and they also hold in some places deposits of ores of zinc, copper, nickel, cobalt, and silver; and the lead-ore is occasionally valuable for silver as well as lead, though seldom containing as much as that from veins in metamorphic rocks. The ores occur partly in veins, but largely in local ore deposits, occupying fissures, passages and chambers, at different levels, along certain courses.

In the great lead regions of Wisconsin and Missouri there are, as shown by J. D. Whitney, no lead *veins*. The passages or cavernous spaces containing ore, owe their forms and size largely to erosion of the limestone by water or acid solutions. With the lead ore occurs barite, calcite, broken chert and limestone, a large amount of zinc ores, and sometimes valuable nickel and cobalt ores. Adolf Schmidt, in his account of the Missouri lead mines, observes that the same solvent waters that made the caves and horizontal fissures or openings, may have held the various associated ores and other minerals in solution. The source of the ores is supposed to have been superficial The po-

sitions of the fissure-like and cavernous openings were in part determined by the joints in the rocks. The ores of Eureka, Nevada (and of some other western mines), are similar in occurrence. But, besides lead, they yield gold and silver, and the chief ore is lead carbonate. With this, and other lead salts, and much red iron oxyd, there is some argentiferous galenite, and auriferous arsenopyrite — the minerals from whose oxydation, says Raymond, the existing products have mainly come.

The filling of the cavities and fissures of amygdaloids, or any igneous rock, has been produced on the same general method with the filling of veins, although the species transferred to the cavities are mostly different because of the peculiarities in composition of the rock adjoining the cavities. The banding of the agates of such cavities is made on the same principle with the banding of a vein, namely: deposition against the walls; and the agate has often a surface of quartz crystals at centre, as a band of quartz in a vein has its comb of crystals pointed toward the middle of the fissure.

The materials that fill the cavities (making the amygdules) and the fissures may for the most part be traced directly to the adjoining rock. The elements are in most cases the same, except that water is added — and this water is part of that which has made the whole rock semi-metamorphic (p. 748). The chlorite, which is usually the first lining of the cavities, has come chiefly from the pyroxene of the rock; the zeolites, from the feldspars, from which they differ little in composition except in the presence of water; the silica, making the chalcedony, onyx, agate, carnelian, opal, hyalite, and quartz crystals, of the cavities, is largely from the altered pyroxene, this mineral having 50 to 60 per cent. of silica, while chlorite has but 25 to 35 per cent.; and the calcite, often abundant, from the lime of the feldspar and pyroxene along with carbonic acid taken into the rock during its eruption. The ingredients that are of outside origin are the water and carbonic acid; and, sometimes, especially in the fissures, various ores, which, if abundant, make them contact veins, as described beyond. The depositions were made as the cooling of the solidified igneous rock went forward. Daubrée has shown that chabazite and harmotome, as well as calcite, are now forming in crystals in the interior of the bricks of Roman masonry at the warm springs of Plombières, Bourbonne-les-Bains, and Luxeuil, in France, and at Oran in Algiers; at Oran the temperature is not above 116½° F., and at Luxeuil, only 115° F.

(3.) *Dike-like Veins.* — Whenever, in the progress of metamorphic changes, a rock was rendered plastic, the material, whether granite, limestone, or of other kinds, would have risen into all fissures that were opened down to it. In this way veins of granite and of other rocks have sometimes been made. When of granite, they differ from veins of infiltration in being like ordinary granite in their uniform grain and other characters, free from all banding and from coarse crystallizations. The granite of such veins is often a good building stone, while that of infiltration veins is too irregular in grain for such a use.

Near the New London (Conn.) light-house, a fine grained whitish granite constitutes veins of this kind coming up through gneiss, while at other places in that vicinity it is in extensive *beds* so associated with the gneiss as to leave no doubt of its metamorphic origin. Again, at Birmingham, Conn., where coarsely porphyritic gneiss and mica schist occur in frequent alternation, a large vein of porphyritic *granite*, structureless, but otherwise identical in aspect with the gneiss, at one place breaks through the mica schist, and has fragments of the schist involved in it. In northern New York there are veins of crystalline limestone of this kind, as described by Emmons.

(4.) *Contact Veins.* — When eruptions of melted rock have taken place, they have often brought not merely the heat of great depths to the surface, but also, various mineral materials encountered on the way up, and especially some of the metals or their ores.

The fissures were in general deeper than those that gave origin to veins of segregation, for the latter did not reach to where melted rock could fill them, and hence had to be filled by what they could get through the slower process. They consequently must have descended to regions of very high temperature. As in a volcanic conduit, whatever at these depths, in the heated subterranean region adjoining the opened passage-way, was ready to pass into a state either of vapor or liquidity, would have been forced, by the pressure to which it was subjected at those depths, to escape, if possible, by the way made for the liquid rock, and would have ascended either along side of the latter, or within its mass; and at the same time, a portion would have been liable to be forced into the wall rock of the fissure wherever it was not of too close a texture to receive it. The mineral material that could take advantage of such an opportunity, or be aided in it by the heat of the ascending melted rock, would be that, as just implied, which was most easily fused or vaporized; and this includes certain metals and their ores, especially those of copper, silver, and antimonial, arsenical, and sulphurous ores of lead, or of lead with silver or copper. The fusing points of pure copper and silver are below 2,500° F., that of copper being, according to Riemsdyk's experiments, at the Utrecht mint, in 1869, 2426° F. and that of silver, 1904° F.; and hence these might have passed into the melted rock in the liquid state; but whether this was the fact, or whether they were in vapor, or in some vaporizable or soluble compound, is not definitely known.

The above is a general explanation of the initial movement in the making of copper mines like those of Lake Superior, in which the metal is in the native state, and the silver mines of Nevada, Mexico, Bolivia, Chili, Transylvania, and of many other regions, which afford various ores of silver with often some native silver. The igneous rock of the Lake Superior region is largely doleryte, and copper is in fissures and cavities in the igneous rock and in the sandstone of the walls. The rock of the famous Comstock lode in Nevada consists of a hornblendic eruptive rock related to dioryte (called propylyte). (See Zirkel's Report (1876), in the Series on the Fortieth Parallel of the King Expedition.)

The materials carried into such fissures may react chemically on one another, and so produce the occurring ores; and successive changes might take place from new accessions of ingredients at different levels.

Besides the kinds of ore-deposits mentioned above, there are, also —

(5.) *Bed-impregnations.* — They are beds in a stratified rock which have become impregnated with ore by some method distinct from that of superficial accumulation. They thus differ from iron-ore beds, which are simply marsh deposits. They occur in many parts of western America, and are worked for silver and other ores. The following sections illustrate a case of this kind. They are from a report made in 1879, by Rothwell and Crouch, on a district in Utah, on Virgin River, 250 miles south of Salt Lake. The formation containing the ore-beds, *o*, is probably Cretaceous (see Gilbert's Rep., 158, 171, 1875).

Fig. 1132.

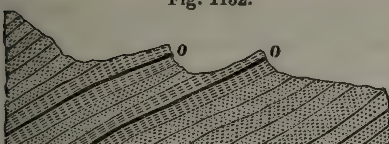
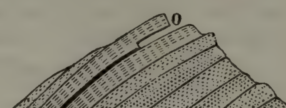


Fig. 1133.



The ore is chiefly silver chlorid or horn-silver. The rocks are sandstone, argillaceous sandstone, and shale, and are more or less upturned. The ore-beds are usually clayey layers or shales, or combinations of layers of sand and clay, and appear to have a wide extent; and the ore is most abundant when the clays contain vegetable remains. Since the silver ore in these beds is the chlorid, it is probable that salt waters were in some way concerned in the ore-making process; and as eruptive rocks are not far away, it is also probable, as J. E. Clayton, in the same report, urges, that hot vapors, derived either from the fissures of eruption or from other wide-spread fracturings made by the eruptive movements, were another factor. The vapors may have penetrated directly the wet rocks from fissures underneath; but it seems to be far more probable that they rendered hot, and in places metalliferous, the waters of salt lakes, and that these waters, passing through the sandy beds, made their deposits in the less pervious clayey beds. Fossil remains are always the first portions of a bed to become penetrated by ore. The beds were impregnated with ores after they were made; and yet it is not certain that there were not repetitions of the process for the several ore-beds during the course of the era in which the rocks were in progress.

In other cases of bed-impregnations, the waters may be those of ordinary fresh-water ponds; but over most of the Great Basin, salt is common in the soil and waters. The regions of hot springs and lakes in California and Nevada illustrate some of the conditions.

The mines of cinnabar, of California, as the facts and reasonings of J. D. Whitney show, are probably other examples of this mode of ore-deposition, and the fissures which brought up the vapors were appar-

ently connected with the volcanic action along the coast region. This ore of mercury occurs distributed in an irregular way through partially altered sandstones, feebly metamorphic slates, serpentine, and hard siliceous beds of Cretaceous age, all of which rocks indicate the action of hot waters. The vapors of mercury were probably from beds intersected at shallow depths by the fissures.

In miners' language, a *reef* is any body of rock that yields valuable ore; and the silver-yielding beds above described are accordingly so-called. The term is of Australian origin, and was first used for veins of gold-bearing quartz.

(6.) *Sediment-formed Veins.* — Fissures have sometimes become filled from above with sand or gravel. Near Astoria, Oregon, occur several large sandstone veins of this kind. (Author's Expl. Exp. Rep., p. 655.) In Southern Utah and in Colorado, according to J. S. Newberry, such veins exist made of coarse gravel and stones; but the stones have become coated with argentiferous galenite and other ores, including silver chlorid, and the veins are worked for silver.

At Leadville, Colorado, deposits of lead-carbonate, silver-chlorid, etc., lie on limestone underneath porphyritic lava. They probably correspond to a contact-vein, made at the time of eruption of the porphyry by means of ascending vapors and hot springs.

By the methods which have been pointed out, the different parts of a lode, whether an infiltration or contact vein, may be made to differ much from one another. The upper part may have its metals in different states of combination from the lower, through mineral solutions received from above, or those made by decompositions in progress, and also through the direct action of atmospheric influences. The copper ore of a vein may be simply chalcocite (Cu_2S) below, and above contain, besides this species, bornite (Cu_3FeS_3), chalcopyrite ($CuFeS_2$), copper sulphates, carbonates, phosphates, or arsenates, and red or black copper oxyd (Cu_2O or CuO). A silver mine may be long worked for its chlorid and bromid of silver, and these ores fail below. A lead mine may for a considerable depth yield lead carbonate, or sulphate, or phosphate, when galenite (PbS) in the lead ore below. The pyrite which is so generally present in ore deposits helps much in these changes, because of its own liability to change, and adds also, through its oxydation, to the red or brown iron oxyd formed, if not the only source of this oxyd (p. 704).

Much light has been thrown on these transformations by various experimenters, and especially by Bischof and Daubrée. Daubrée found, in the thermal waters at Bourbonne-les-Bains (department of Haute-Marne, France), in the bottom of a part of which, in Roman times, bronze, silver, and gold coins had become buried, the following mineral species, which he proved to have been derived from the alteration of the metal of the first two of these kinds of coins through the agency of the mineral waters, the temperature of which is 140° F.: the copper ores, *chalcocite*, *chalcopyrite* (copper pyrites), *bornite*, *tetrahedrite*, *atacamite*, *cuprite* (red oxyd of copper), *chrysocolla*, *native copper;* the lead ores, *cerussite* (lead carbonate), *anglesite* (lead sulphate), *galenite*, *phosgenite*, and *pyrite*. All these species came from the action of the same water, at a comparatively low temperature. The bronze was found to consist of copper, tin, and lead, or of copper and zinc, with a trace of iron. The materials obtained in the analysis of these waters are chlorids and sulphates of the alkalies and of lime and magnesia, with bromids, and carbonates of lime and iron, an alkaline silicate, besides traces of arsenic, manganese, iodine, boron, lithia, strontia, cæsium, rubidium, and, in exhalations, some sulphuretted hydrogen, nitrogen, and oxygen.

Similar results were observed by Daubrée at the warm springs of Plombières, Depart-

ment of the Vosges, and at some other localities. They give a good idea of the various reactions which may take place during the filling of a vein, and through subsequent changes in its condition.

On page 709 mention is made of recent depositions, from hot springs, of quartz crystals and chalcedony in layers or crusts. At Clear or Borax Lake, as observed by J. A. Phillips (Quart. J. Geol. Soc., 1879), the siliceous deposits frequently contain pyrite and *cinnabar*, and the sulphur bank, which has there been formed through the heated vapors, has been worked as a mercury mine. J. D. Whitney reported the occurrence of *gold* in cinnabar which was supposed to have come from near "Sulphur Springs," four miles south of Bear Valley, between Clear Lake and Colusa; and Mr. M. Atwood has removed the doubt as to the source of the specimen by finding in a fissure at the place mentioned (as reported by Mr. Phillips), cinnabar *overlaid* by a brilliant deposit of metallic gold. In Nevada, at Steamboat Springs, according to Mr. Phillips, fissures are being lined with a siliceous incrustation, while at the same time steam and gases, (carbonic acid, and sulphuretted hydrogen), with boiling water, are escaping; and "they have been subjected to a series of repeated widenings," and become lined to a thickness of several feet with silica, which is in bands, amorphous and crystalline alternating, and contains some hematite, pyrite, and chalcopyrite According to Mr. Laur (Ann. des Mines, 1863), the silica of these fissures contains also traces of gold; so that the facts, as he has stated, exemplify the essential points in the origin of auriferous quartz-veins. This view was presented by B. Silliman and W. P. Blake, in 1864, with reference to the banded quartz veins (gold-bearing) of Bodie Mountain, north of Mono Lake, which are *contact veins* intersecting porphyry.

Further, while the filling of cracks and openings with quartz, making quartz veins, generally results in a very effectual mending of the fractured strata, the introduction of bands of ore and of spars, makes them weak planes in the rock, and weak planes of very great depth and extent. In this latter case, they are liable to be opened anew during subsequent disturbances of the region, and to receive a reheating of the old part and the adjoining rock through the friction occasioned, or rising vapors. Under such circumstances, new material may be introduced to fill the opened spaces, and so add to the number of bands in the vein, and new changes may be set at work among its pre-existing materials. By this means a vein may be doubled or tripled in its bands, and suffer great changes in its ores. The six bands represented in Fig. 1130, are ascribed by De la Beche to several reopenings of the vein; and of those in Fig. 1131, two or three openings seem to be indicated, one for *d*, one for *b*, *c*, *b*, and perhaps a different one for *a*. Veins containing no ores often show that they have undergone some disturbing movements by the changes in the old minerals in many parts to new silicates or other species.

The crystals of earlier deposition are often much eroded in the process of change, where not wholly removed. In a small vein in the trap of Mill Rock, near New Haven, Conn., containing prehnite, laumontite, stilbite, quartz, and some traces of copper ores, quartz crystals occur, at times, having the pyramid removed by erosion, and a hexagonal depression made in its place which is bounded by thin projecting edges of the prism. No fluorids are present; and nothing is yet known with regard to the eroding agent.

The existence of veins of ore, which are *wholly eruptive*, that is, which came up as a melted mass, like dikes of igneous rock, have not been above recognized. Even quartz veins are sometimes described as such; but this mode of origin is at variance with all their characters and with their modes of occurrence, contents, and distribution. It is possible that the native iron, which is found by the ton in Greenland doleryte, may have come in its native state from the deep source of fusion. Doleryte and many other igneous rocks contain magnetite, and often also pyrite, in disseminated grains, with traces of native iron, but never enough to make them *iron ores*. J. Lawrence Smith has suggested that the Greenland iron is a result of deoxydation by carbonaceous matters taken into the doleryte while on the ascent to the surface.

The subject of veins and local ore deposits does not include the ore deposits which are among the earth's strata as part of its stratified rocks. That the true limits of the subject may be understood, the kinds of *stratified* ore deposits are here enumerated.

1. Beds of the iron ores, hematite, magnetite, limonite, and siderite (iron carbonate

or spathic iron), which are the sources of the iron of the world, a small part of the iron carbonate (which occurs in veins) excepted. Hematite and magnetite occur in metamorphic rocks; hematite, limonite, and siderite, in non-metamorphic.

2. Copper ore in the form of malachite, azurite, cuprite, chalcopyrite, and sometimes tetrahedrite, in the Permian of Germany and Russia.

3. Auriferous and platinum gravel deposits (the source of a large part of the gold of commerce), which are merely gravel beds, like any other gravel of the stratified drift, but made from rocks that were intersected by veins of gold-bearing quartz.

Minerals have their natural associations, and the study of these — or the *paragenesis of minerals* — has great geological importance. But it leads off into the broad subject of chemical geology, which is of extent enough to fill several volumes.

The most important descriptive work in connection with the subject of mineral veins which has appeared in the United States is the report on the great Nevada Mining Region, published as Vol. III. of the Reports of the U. S. Geological Exploration of the 40th Parallel, under the title, Mining Industry, by JAMES D. HAGUE, with Geological contributions by CLARENCE KING, 4to, 1870.

J. D. WHITNEY'S Metallic Wealth of the United States (8vo, 1854), is an excellent work, much needing a revision bringing it down to the present time.

R. W. RAYMOND'S Reports to the Government On the Mineral Resources West of the Rocky Mountains, 1869 to 1876, contain a large amount of information on the mines of the country, though treating mainly of resources and mining operations.

DE LA BECHE'S more important works are his Report on the Geology of Devon and Cornwall, and the Geological Observer; the last edition of the latter appeared in 1851. The Transactions of the Geological Society of Cornwall contain many valuable memoirs on veins, among which those of J. W. HENWOOD, in Vol. V. (1843), have special interest. The titles of the works of A. DAUBRÉE and BISCHOF, referred to in the preceding pages, are given on pages 769, 770. The excellent treatise on Ore Deposits, of B. VON COTTA, translated by Professor Frederick Prime, Jr., from the 2d edition (but with additions and emendations by the author), was published in New York in 1870.

VI. THE EARTH A COOLING GLOBE: ITS CONSEQUENCES; OR CAUSES AND EFFECTS OF MOVEMENTS IN THE EARTH'S CRUST.

1. ACTUALITY OF CHANGES OF LEVEL.

All geological history testifies against the stability of the rocky crust of our globe; and if the earth has cooled from fusion, as is believed, abundant reason for this unstableness exists. The effects reach backward to unknown limits, and downward beneath other agencies of change. They include indefinite grades of variation in level, up to the making of mountains and continents and the deepening of the oceanic depressions, besides, also, the fracturing, faulting, and upturning of rock formations; and they embrace, indirectly, the crystallizing of sedimentary strata, the making of veins, the opening of volcanic vents, and the determining of variations in climate, in faunas, and in living species.

The following facts are here stated anew, to bring to view the reality and extent of changes of level.

(1.) A section of the coal formation of Illinois, described by Worthen, contains 16 coal beds, large and small, *separated by* fragmental beds and limestones containing *abundant remains of marine life*. The coal beds indicate eras of *emerged* land, the marine fossils, intervening eras of *submergence*, and their number shows that, at least, sixteen alternations between the two conditions there took place in the Carboniferous period. Facts make it certain that the great interior sea of the continent communicated at that time freely with the ocean to the south. The same region thus went up and down, changing the dry land outline and the sea depths; and the changes went on with extreme slowness, for coal beds, as well as the much thicker marine beds, were slow in accumulation. Facts of similar import are afforded by all the successive formations, from the Primordial upward, and alike on all the continents.

(2.) During Paleozoic time, between 30,000 and 40,000 feet in average thickness of sedimentary beds were laid down, according to geologists of New York and Pennsylvania, along the region now covered by the Appalachian Mountains; of these, many bear evidence of shallow water origin; and in the last period of that prolonged era, the Carboniferous, peat-making marshes were spread out over the top of the great pile, but *little above the sea level*. A sinking of 30,000 to 40,000 feet is thus proved for that region. At the same time the region of Illinois and other parts of the Mississippi basin underwent a sinking not exceeding 5,000 feet, and northern New York and Canada little if any, and thus there were unequal changes of level during the same era in different parts of the same continent. Further, the sinking in both regions went on with the alternations in level indicated in paragraph (1).

(3.) The Red Sandstone formation (Triassico-Jurassic) of the Connecticut Valley was made in an estuary, and therefore below the sea-level; and now, in its northern part, in Massachusetts, it has, in Mount Toby, a height of 1,300 feet above the sea, while in its southern part, near New Haven, it is less than 400 feet in height; the level follows approximately the level of the crystalline rocks either side of the Connecticut Valley, and the trap ranges associated with it show a similar change of level, though overtopping the sandstone because of their superior hardness.

(4.) In the Cretaceous period, the region of a large part of the Rocky Mountains and of the Atlantic, Gulf, and Pacific borders of the continent were beneath the sea, but mostly near its surface; and the marine life of the sea contributed to the forming Cretaceous beds. *Now*, the marine beds, filled with Cretaceous fossils, are at a height of 10,000 to 11,000 feet in the Rocky Mountain region, at a maximum height, on the Pacific border, of only 5,000 feet, in Alabama of 700 to 800 feet, and in New Jersey not over 400.

(5.) In the early Tertiary, the European and Asiatic seas grew Nummulites, and limestones were made of the multiplying disks. Now, those Eocene Nummulitic beds are at a height of 9,000 feet in the Pyrenees, 11,300 feet in the Alps, 16,500 feet in the Himalayas in Western Thibet, and a few hundreds only near Paris.

(6.) In the Quaternary, before the disappearance of the ice, the region along the St. Lawrence, near Montreal, as shell deposits show, was about 500 feet *below its present level*, that of the northern half of Lake Champlain, on the same evidence, over 300 feet; the coast of Maine, 200 to 220 feet; Southern New England, along Long Island Sound, not over 25 feet. There has, consequently, been since then (1) a change of level at these places of unequal amount; and (2) one varying in height more than 450 feet in a difference of latitude of five degrees. And this was, in all probability (pp. 553, 561), only a part of a much wider change of level.

(7.) The region of atolls over the tropical portion of the Pacific Ocean, having a length from east to west of 5,000 miles, has undergone a subsidence, as Darwin has indicated, from a few hundreds to thousands of feet in depth, since the coral animals began to make there their coral reefs; while the subsidence on the borders of the region of atolls, as the limited reefs of the high islands show, was comparatively small.

(8.) Movements, up or down, are now going on along the coast of North America, Scandinavia, Greenland, and elsewhere. Alexander Agassiz states that at Tilibiche, in Peru, there is a coral limestone, 2,000 to 3,000 feet above the sea-level, extending

along for twenty miles, in which occur corals modern in aspect; and that the existence in Lake Titicaca, of eight species of a salt-water genus of Crustaceans, Allorchestes, suggests the presence of the sea over this region, 12,500 feet in height, at no very distant period. On north circumpolar changes of level, see, further, H. H. Howorth, in the Journal of the Royal Geographical Society, xliii., 240.

The facts of geology show that the earth's surface has never yet been at rest. They prove,

First: The actuality of change of level through movements in the earth's exterior.

Secondly: The fact of unequal changes, in progress simultaneously, in different parts of the same continent or continental region.

Thirdly: The fact of vastly greater changes of level in geological time after the commencement of the Tertiary than in the earlier periods of the Paleozoic and Mesozoic.

Fourthly: The fact of similar simultaneous movements on opposite sides of the Atlantic; as indicated by the parallelism between Europe and America in the conditions and kinds of rocks in progress in some periods and exemplified remarkably in the Subcarboniferous limestones; the coal-measures; the Triassic strata; the contrast between the Jurassic and Triassic beds as to prevalence of fossils and in other respects; the Glacial phenomena; the Champlain period of subsidence.

No lessening of the amount of oceanic waters, whether by abstraction of part to make ice, or by any other method, can explain the facts. Such causes, whose effects should exist along the borders of all the continents alike, are often appealed to; but *no statement of parallel facts from the different continental borders* has ever been presented in order to sustain the opinion. The *deepening of the ocean's bed* may produce the parallel movements of America and Europe just referred to; but if so, the cause is, none the less, change of level in the earth's crust — though change in the part beneath the ocean.

No change in the position of the centre of gravity can produce the effects mentioned; for this would give an even curve to the surface of the water far wide of that required by a difference in water level of 450 feet between the parallels of 45½° and 41½° (the former that of Montreal, the latter that of the southern coast of New England), with only 25 feet for the latter.

Inequalities in the contraction of the earth attending its original cooling cannot account for the existence of mountains; and appeals to the earth's rotation during early periods, and to other astronomical conditions, are equally unsatisfactory. For (1) slowly progressing subsidences have taken place beneath the continents that much exceed in extent of movement the elevations; (2) subsidences and elevations have taken place alternately; and (3) the great mountains of the globe

did not take the larger part of their elevation until the Tertiary era had opened. The question whether the first existence of continents and oceanic depressions may not be explained by a reference to the earth's contraction is not here considered.

2. FACTS ABOUT MOUNTAINS.

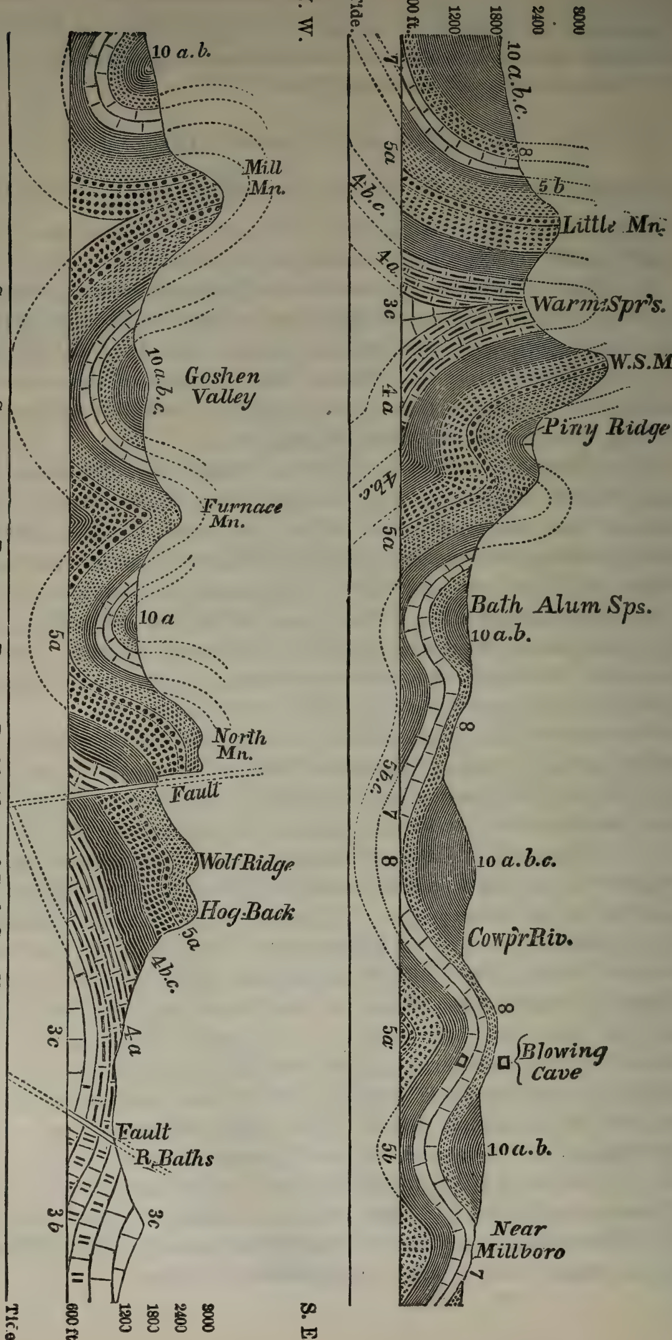
(1.) Characteristics of Disturbed Regions and Mountains.

Changes of level have sometimes taken place on a grand scale without appreciable change in the positions of the rocks of the region moved. Such were the oscillations in the Quaternary over the higher latitudes, and other movements which have given elevation or depression to large portions of continents at once. But over all the continents, the rocks almost everywhere bear evidence of the action of disturbing forces, both in their inclined positions, and in fractures; and over large portions the beds stand at high angles.

These disturbed conditions of rocks include (1) *flexures* of all grades, from the feeblest bulgings of great areas to the bending up of strata into many steep successive folds; *fractures*, from local cracks to those that descend to indefinite depths; *faults*, or displacements along fractures, of all amounts, up to 20,000 feet or more. Mountain regions are regions of disturbance; in them occur all degrees of folding, fracturing, and faulting, from the feeblest to the most extreme. An explanation of the origin of mountains is to a large extent, therefore, a discussion of the nature and origin of these phenomena.

1. Flexures. — The characteristics of the flexures of rocks are illustrated in the preceding pages on Historical Geology. On 93–96, 98, and 101, are representations of some of the forms; these occur with a breadth of a few feet, or a span of many miles. Others are shown on pages 213–215, from examples in the Green Mountains, and on page 396 from the Appalachian range. The following section of a part of the Appalachian region of Virginia, by Prof. J. L. Campbell, is here introduced as a further illustration of the subject. It represents the rocks for a breadth of thirty miles across the range, from a point southeast of Rockbridge Baths to two miles northwest of Warm Springs in Bath County, Virginia. The vertical heights are marked on the side. The numbering of the formations corresponds with that on page 142; the limestone areas in the cut are blocked, the shales ruled, and the sandstones dotted. (For particulars as to the geology of the region, see the memoir by Prof. Campbell, Amer. J. Sci., III., xviii., 119, 1879.) Farther to the southeast, in the same line, the folds are more closely crowded, and become a series of nearly vertical beds. The Reports of the first and second Geological Surveys of Pennsylvania contain many figures of Appalachian flexures.

Fig. 1134.



Section of Silurian and Devonian Rocks—Rockbridge and Bath Cos., Virginia.

The folds in such regions are variously worn away in nature, and in this lies a large part of the difficulty of ascertaining the relations of the included beds. On account of the perplexities to be encountered, especially in regions of metamorphic rocks, or where the upturnings have been greatest, an additional illustration of the subject is here introduced. In Fig. 1135 there are five strata of like dip, 1, 3, and 5 consisting of schist, and 2 and 4 of limestone. Suppose that the surface only is exposed to view, as is true in many such cases: What are the several possible conditions as to the stratification? Some of these conditions are as follows:—

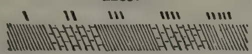
(1.) Five independent strata lying in the order of deposition.

(2.) Three faults (see p. 100), making 1, 3, 5, one stratum, and 2, 4, another.

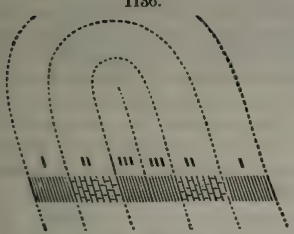
(3.) One fault, making 1 and 3 one stratum, and 5 another.

Figs. 1135–1141.

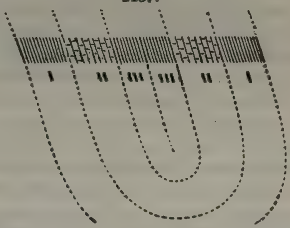
1135.



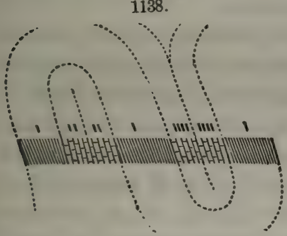
1136.



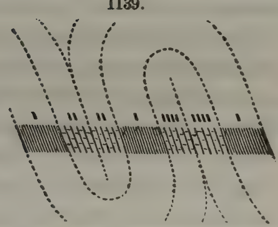
1137.



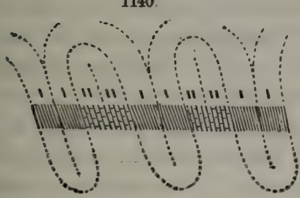
1138.



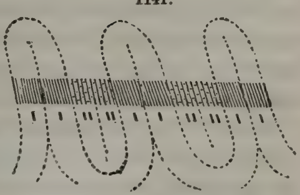
1139.



1140.



1141.



(4.) One anticlinal, as in (Fig. 1136), making 1 and 5 one stratum, 2 and 4 another. and 3, a stratum folded on itself; whence No. 3 is the oldest of the series.

(5.) The same as the last but reversed, as in (Fig. 1137), the fold being a synclinal, and No. 3, the *newest* or overlying member of the series.

(6.) A synclinal and anticlinal, as in Fig. 1138, making Nos. 1, 3, 5, the same stratum, but 2 distinct from 4, and each 2 and 4 folded on itself.

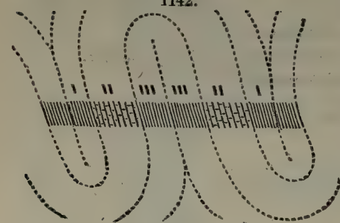
(7.) The same except that stratum 2 is made a synclinal and 4 an anticlinal, as in Fig. 1139.

(8.) Synclinals and anticlinals, as in Fig. 1140, making but two strata of the whole, 1, 3, 5, being one, and 2, 4, the other, the latter the underlying one of the two; and each is doubled on itself.

(9.) Fig. 1141 the same as last reversed, the anticlinals becoming synclinals, and the synclinals anticlinals.

(10.) Synclinals and anticlinals, as in Fig. 1142, in which there are three strata, 1 and 5 being the same, and each, as well as 3, folded on itself, while 2 and 4 are the same stratum.

1142.



(11.) The same reversed, making 1 an anticlinal and 3 a synclinal.

(12.) There may, further, be double flexures, that is, two synclinals and an anticlinal, or two anticlinals and a synclinal, in either one or each of the strata; or (13), the whole series, from No. 1 to No. 5, may be half, or less, of an overturn fold, either anticlinal or synclinal.

The problem with regard to the relations of such a series of strata is to be solved by comparing them as to fossils; or if they contain none, by looking over the region for places where the folds, instead of being steep, are *shallow* synclinals and anticlinals, giving to the eye the true order of superposition, and multiplying such observations to settle the question that arises as to an overturn fold; studying the resemblances in texture, color, thickness, etc., in the different strata 1, 3, 5, or 2 and 4, and noting differences or resemblances in the two sides of the same stratum, or in the succession of the different parts composing them. To remove all doubts where there are no fossils is often difficult. The difficulty is increased by the fact that a stratum may vary its thickness, or thin out in one direction or the other, and also vary greatly in its mineral constitution. The fact of conformability or not is always to be studied; but there may be apparent unconformability from flexures in the line of strata, and from faults, which is no mark of difference of age.

The greater flexures in such a region are of all sizes, from a fraction of a mile to twenty miles or more; and there are minor crumplings of a few inches or feet in breadth. The flexures have a general parallelism to the axis of the mountain range. Instead of one fold for the range, or a like length to parallel folds, there is generally a succession along the mountain region, like the series in the case of fissures illustrated in the figures on page 19, the several folds in the series overlapping one another. The flexures have rarely, if ever, the axial line horizontal (a result that would require the utmost evenness in the beds and in the action of the flexing force); and besides being inclined, the axes of adjoining flexures often incline in opposite directions, a necessary mechanical effect in the process of warping.

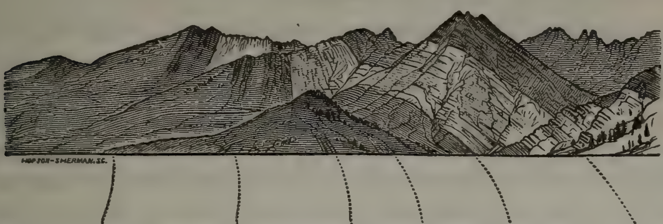
Further: in the folds of a mountain region the axial plane (see figures on p. 93, and the section, p. 786) is seldom vertical, their opposite slopes in a transverse section, being unlike. The folds are thus *unsymmetrical;* but those of one region have the steeper side generally facing in the same direction. Besides, the mountain range has a corresponding want of symmetry; a side of steeper folds, and an opposite in which they are gentle or gradually fade away.

These points are illustrated, not only in the Appalachians and Green Mountains, but also in the Jura Mountains, the Alps, Apennines, and

Carpathians, and in the folded strata of other regions, the Sierra Nevada, which is peculiar in being a single mountain mass, the western side has a slope of 100 to 250 feet to the mile, and the eastern a slope, for a large part, of 1,000 feet to the mile.

Where flexures have an inclined axis and axial plane, a twist or torsion of the strata must often have taken place. A marked example of torsion is represented in the cut below (by Gardner), representing upturned beds in the Elk Mountains, Western Colorado, from Hayden's Survey of 1873. Through a twist in the upturning, the Cretaceous,

Fig. 1143.



Upturned strata of the west slope of the Elk Mountains, Colorado. The light-shaded stratum, Triassico-Jurassic; that to the right of it, Carboniferous; that to the left, Cretaceous.

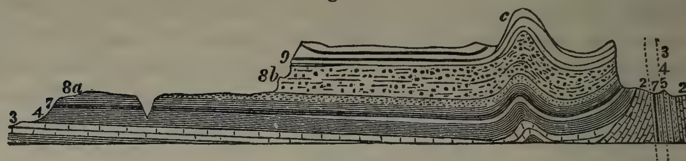
which is the overlying rock in the back part of the scene (to the left), is really the underlying in the front part *and the Carboniferous the upper part*, the pressure having so pushed forward the mass that the order of superposition is the reverse of the order of age; and the Carboniferous beds of the front ridge incline 45° beyond the vertical.

Again, in regions where the folding was feeble in degree, there has sometimes been an upward bend along a line of much length, with no corresponding downward slope. Such folds are described by Powell as occurring in the Colorado basin, and are illustrated in the figure from his Report given on page 792.

Extensive elevated plateaus are a feature of the gently folded margins of mountain ranges. They sometimes pass by a gradual passage into the more folded region of the mountains; but often they stand apart in consequence of a great fault or series of faults. The region of Alleghany Mountain, together with its extension northward and eastward to New York and the Catskill Mountain mass, and southward through the Cumberland Table Mountain of Tennessee to Alabama, lies in the western section of gentle slopes of the Appalachians. The following figure, from Safford, represents the abrupt succession from the folds of Eastern Tennessee to the nearly horizontal and boldly browed "Cumberland Table-land," just west. The folded region, which is that of the more upturned portion of the Appalachian range (lying west of the Archæan range on the eastern bor-

der of the State) is a country 50 to 60 miles wide, of open northeast and southwest valleys, with long intervening ridges or mountains shaped by denudation; and it is called as a whole the "Valley of

Fig. 1144.



Cumberland Table-land, Tennessee; c, Crab Orchard Mountain; 2 to 9, as on p. 142.

East Tennessee," because, owing to the denudation, much of the country is low compared with the equally wide Cumberland Table-land. As described by Safford, the surface of the Table-land is 900 to 1,200 feet above the valleys on the east, and at one point nearly 2,000 feet, and it averages 2,000 feet above the sea-level. In consequence of a fault at its eastern foot, stratum No. 4 (Hudson River) is there in contact with 2, or the Calciferous; and then, just east, another fault has put the latter stratum along side of No. 7, or the Devonian Black shale.

The Catskill region is another plateau portion of the margin of the Appalachians. The rocks, which are Upper Devonian at top, rise in some of the peaks to a height (as shown by Guyot) exceeding 4,000 feet; and yet they are nearly horizontal, and actually the eastern margin of the great plateau of Southern New York. Denudation, as stated on page 647, has given them their mountain-like shapes; and the depths of the valleys, as well as the height and boldness of the escarpment facing the Hudson, shows that there has been an immense amount of it. The Uinta Mountains are a broad plateau, 150 miles from east to west (the direction of its axis), on the east of the Wahsatch Mountains, against which they terminate abruptly. There are gentle flexures at the north and south extremities.

Such facts prove that great plateaus and regions of steep folds may be from one and the same process of mountain-making. The Appalachian Mountain region has received part of its altitude since the Appalachian revolution ended; but relative heights may not be very greatly altered, except through denudation.

2. **Fractures. Faults.** — Fractures characterize all mountain regions. Along the axes of folds they are very common. This is especially true of anticlinals, in which the fractures naturally open upward, and were often left gaping, or were filled so as to become the courses of veins. Hence, great veins are often an indication of the centre of an anticlinal.

Other great fractures that were never opened so as to become veins are indicated by the existence of an extensive displacement or fault along them. The fault toward the western limit of the Green Mountains is mentioned on page 214; and others, of still greater extent, in the Appalachian region to the southwest, on page 399. From a recent observation by J. G. Lindsley, it appears that the fault reported to occur at Rhinebeck, on the Hudson, and to be connected with the Green Mountain region, occurs really at Rondout, on the west side of the Hudson; that there is here unconformability between Lower Silurian and Lower Helderberg beds; and that the upturning and faulting of the latter may have taken place, as T. Nelson Dale suggests, when the Catskill plateau received its high position.

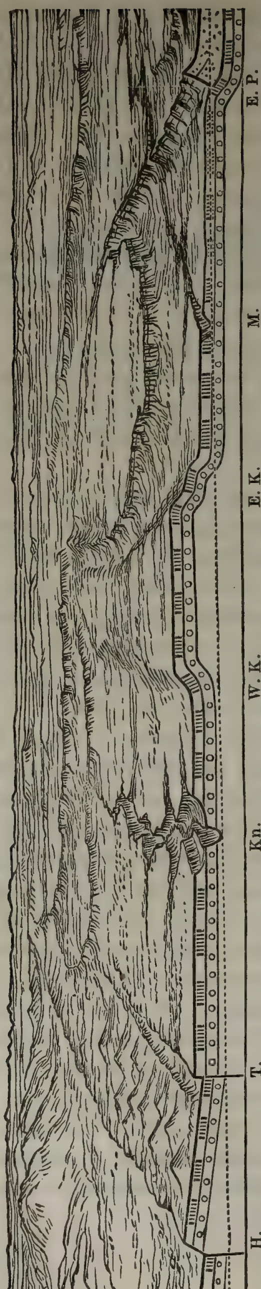
According to King, a fault of 40,000 feet exists in the Wahsatch range. It extends for "100 miles from north to south," following the axis of a great fold; and, when made, the western part of the arch sunk to the depth stated.

Again, the fractures connected with mountain-making sometimes give exit to igneous eruptions. But these deeper fractures have occurred where there was little done in the way of folding; the more of one, the less of the other. It is not known that there were any such outflows in the making of the Appalachians, while they were of great extent and made many trap ranges in connection with the disturbance of the Triassico-Jurassic beds of the Atlantic border, and were vastly more extensive over the globe in Tertiary times.

Besides these great fracturings, there are all grades, down to local breaks in beds and displacements of masses; and still further, to crushings and shovings, and tumblings together of the broken fragments.

The region of the Colorado basin, and other portions of the dry country west of the summit of the Rocky Mountains, are particularly good for the study of fractures and faults, as well as flexures, because the earth's ribs are there bare of vegetation, and hence open almost everywhere to inspection. The reports on these regions by Powell, Gilbert, Howell, and Hayden, contain numerous illustrations. The parts into which the formations over hundreds of square miles have been broken by the disturbing forces lie together, pitching in various ways, with the outlines so well preserved, in spite of erosion, that but little study is required to restore to the mind the original unbroken condition of the beds. Powell speaks of many areas "where a zone has been broken into blocks, and these blocks tipped and contorted in diverse ways and directions, like the blocks of ice crowded in an eddy of a river at the time of its spring flood."

Fig. 1145.



Section from west to east across the Colorado plateau, north of the Grand Cañon, with bird's eye view of terraces and plateaus above. Horizontal scale 16 miles to the inch; vertical, 4 miles to the inch. H., Hurricane fault; T., Toroweap fault; Kn., Kanab Cañon in the Kanab plateau; W. K., West Kaibab fold; E. K., East Kaibab fold; M., Marble Cañon; E., Echo Cliff; P., Paria fold.

In most regions of faults, the strata have been so denuded that they are indicated only by the difference in age of the strata brought into conjunction. But, if not thus worn away, they would form lines of abrupt elevation. Powell has described monoclinal m o u n t a i n ridges in the Colorado Basin and Uinta Mountains, which were thus made; and other facts have been brought out by Gilbert.

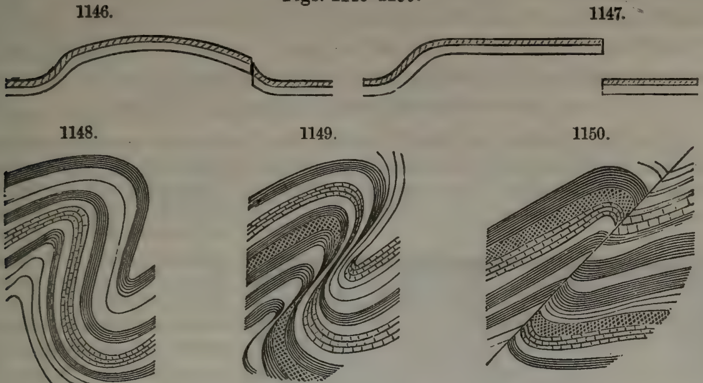
The annexed cut, by Powell, represents a portion of the Colorado Basin, with its one-sided folds (p. 789), its faults and monoclinal uplifts along the faults. The names of the faults at H., T., and folds at W. K., E. K., and P., are given in the description underneath the cut.

A bend often becomes a break, and sometimes also the course of a fault. Powell draws attention to this, in the case of the Colorado Basin, pointing out one such at W. K. (West Kaibab), E. K. (East Kaibab), and P. (Paria fold). Fig. 1146, from his memoir, is intended to illustrate the displacement in the Uinta Mountain, and Fig. 1147 the Kaibab displacement. The elevation by the faulting at W. K. is 2,000 feet; at E. K., 3,000 feet; at P., 1,800 feet.

Another example of the change of a fold to a fracture and fault is illustrated in Figs. 1148–1150 representing a case in the Alps, figured by Heim in his work on Mountain-making.

Fractures may cut through the rocks vertically. But they usually have more or less obliquity — frequently as much as 45°, and sometimes a dip of only 25° or 30°. The case in the Alps, here repre-

Figs. 1146–1150.



Folds passing into Faults.

sented, is one of very nearly 45°. The fissures occupied by the trap of the Connecticut Valley, near New Haven, Conn., vary in dip from 30° to 70°; in one north-and-south dike, 300 or 400 feet wide, it averages 30°; in another, 45°; in two east-and-west dikes, each about 200 feet wide, 50° and 67°.

The fracturing agency has produced widely unlike effects on different kinds of rocks. If hard and comparatively unyielding, long, even fissures are often made; if brittle, like a limestone and some sandstones, they have been very irregular and the rock much broken; while sand-beds that were not firm have had the fractures obscured by compression, or a rearrangement, and clayey beds have been stretched as well as compressed. The fracturings, as seen at the surface, may be very various in direction and variously subdivided, owing to the irregular breakings and faultings of the surface rocks, when in the crystalline rocks beneath, and in the earth's crust, they were very regular, and for long distances uninterrupted.

3. Jointed Structure. — Systems of joints (explained and illustrated on page 88) belong especially to the rocks of disturbed regions. Slaty cleavage is a variety of it, occurring in fine-grained rocks. It has no reference to the bedding, being transverse to it, or parallel to it; but the latter, only when the beds stand at a high angle. In granite, vertical joints are very common. But a horizontal cleavage is often quite distinct; and it is sometimes so decided in granite-like gneiss that were it not for the existence of undoubted nearly vertical lines of bedding in the gneiss, the horizontal planes would be taken

for planes of bedding. This horizontal jointing characterizes, as Whitney states, the lofty granite domes of the Yosemite region; but here it is slightly curving, corresponding with the curvature of the domes. A brittle, semi-crystalline limestone is often broken into small rectangular fragments in the joint-making process; and quartzyte has often its bedding shaken out of it, and a nearly vertical bedding, or rather jointing, substituted. Owing to the differences in rocks, one bed may be full of them, and another, above or below, without them.

The schistose structure, or *foliation*, of mica schist, gneiss, and other related rocks, may sometimes correspond to slaty cleavage; but, in general, it is due to the original bedding of the materials. This is proved in numberless instances by the alternations in these rocks of finer and coarser layers; that is, the gneiss often contains thin layers of mica schist, or mica schist thin layers of gneiss, in many alternations, or more and less feldspathic layers of these rocks alternate with one another, or garnetiferous and non-garnetiferous layers, and so on. The annexed figure illustrates a common case of the kind (from Derby, Conn.), in which some of the layers of gneiss are porphyritic. No such alternation in material could be occasioned by any joint-making process.

Fig. 1150 A.

Gneiss of Derby, Conn.

4. Distortion and Fracture of Fossils and Crystals. — These consequences of the compression and stretching, direct and oblique, of rocks, are exemplified by figures on page 99. So crystals in crystalline rocks, as well as their veins, bear evidence of movements after they took their shape and size.

5. Solidification. Metamorphism. Igneous Ejections. — These common results of mountain-making movements have already been considered.

(2.) Preparation for the Event of Mountain-making.

1. Material for a Mountain Range Slow in Accumulation. — A mountain range of the common type, like that to which the Appalachians belong, is made out of the sedimentary formations of a long preceding era; beds that were laid down conformably, and in succession, until they had reached the needed thickness; beds spreading over a region tens of thousands of square miles in area. An individual mountain range is a very large object in nature. The region over which sedimentary formations were in progress in order to make, finally, the Appalachian range, reached from New York to Alabama, and had a breadth of 100 to 200 miles; and the pile of horizontal beds along the middle was 40,000 feet in depth. The pile for the

Wahsatch Mountains was 60,000 feet thick, according to King. The beds for the Appalachians were not laid down in a deep ocean, but in shallow waters, where a gradual subsidence was in progress; and they at last, when ready for the genesis, lay in a trough 40,000 feet deep, filling the trough to the brim.

It thus appears that: —

2. Epochs of mountain-making have occurred only after long intervals of quiet in the history of a continent.

Mountain-making closed the Archæan era. After the end of the Archæan, or the beginning of the Primordial, the first period of disturbance in North America of special note was that at the close of the Lower Silurian, in which the Green Mountains were finished; and if time from the beginning of the Silurian to the present included only forty-eight millions of years, the interval between the beginning of the Primordial and the uplifts and metamorphism of the Green Mountains was at least (judging from the *relative thickness of the rock deposits*, p. 381) twenty millions of years. The next epoch of mountain-making on the Atlantic border was after, or in the course of, the Devonian in Nova Scotia and New Brunswick; on the above basis, it occurred thirty millions of years from the beginning of the Primordial. The next epoch of disturbance was that at the close of the Carboniferous era, in which the Alleghanies were folded up; by the above estimate of the length of time, thirty-six millions of years after the commencement of the Silurian. The next on the Atlantic border was that of the displacements of the Triassico-Jurassic sandstone and the accompanying igneous ejections, which occurred before the Cretaceous era — at least five millions of years, on the above estimate of the length of time, after the Appalachian revolution. These numbers are mentioned here, not as even an approximate estimate of the real length of the interval, but only of relative lengths, and especially to make apparent the fact that these intervals were *very long*.

On the Pacific border of the continent there was mountain-making at the close of the Jurassic, when the Sierra Nevada was made; and, over the coast region, at the close of the Miocene Tertiary, when, according to J. D. Whitney's latest Report (on the Auriferous Gravels), the Cretaceous and Miocene formations of the coast region were together folded and made into mountains. But for the Rocky Mountain region, no proof has yet been reported of any epoch of disturbance between the end of Archæan time and the close of the Cretaceous, at which the Wahsatch and Uintah Mountains were made; and, more than this, the evidence indicates that through all that long interval, covering nine tenths of all geological time after the Archæan era had closed, the rocks of those mountains were being laid down in consecu-

tive beds, all conformable to one another. The next mountain-making of the summit region followed the close of the Miocene. Finally, the whole Rocky Mountain region, for a breadth of more than a thousand miles, was undergoing elevation during the Tertiary, and did not reach its ultimate height before the beginning of the Quaternary.

It is thus apparent that mountain-making has taken place after immensely long periods of quiet and of gentle oscillations, all of which were periods of gradual preparation for the great event.

3. Repetitions of the Event in the same Great Continental Region, or on the same Continental Border.

The facts just stated illustrate the repetitions that have occurred on the Atlantic and Pacific borders of North America.

Another important truth connected with the successive events is this: that the resulting ranges have a general parallelism to one another, and are parallel to the outlines of the original V-shaped Archæan dry land, as explained on page 160. Even the great bends in the present course of the Atlantic border are repeated in those of the Triassico-Jurassic areas; and in those of the Appalachian range, whose northern part has the trend of Long Island and southern New England, and the southern, that of the Atlantic coast farther south; and, more to the north, in the course of the Green Mountains, which corresponds to the Adirondacks, but trends more northeasterly on the northern borders of New England. The repetitions were hence not only in the event, but in its chief characteristics.

4. Results.

From these mountain-making events, and their repetitions in the same wide continental region, have come the great mountain masses of the globe, and even the Continents, which are the combined results. The following kinds of mountain masses are to be distinguished: —

1. *Individual Mountain Ranges. — Monogenetic and Polygenetic Mountains.* — The Appalachians, a range of many mountain ridges, and valleys, constitute one *individual* among mountains, because a result of one genetic process, or, in a word, *monogenetic*. An individual range thus embraces all the ridges or elevations, or the whole area of comformable rocks, that received their flexures or upturning in the same mountain-making epoch. The Green Mountains are an example of another monogenetic or individual range. The Adirondacks, the Highland Range (of New Jersey and New York) and its continuation southward, with whatever Archæan areas to the northward were cotemporaneously upturned, probably constitute another monogenetic range. The Mesozoic trap and sandstone areas are parts of another line.

But the Adirondacks and Highland ranges, the Green Mountains, and the Appalachians, together make up the Appalachian *chain;* and the latter is therefore a *polygenetic* mountain mass or system.

On the Pacific side, the Wahsatch, Uintah, Elk, and other mountains, are parts of an individual or monogenetic mountain range; the Sierra Nevada is another; the coast ranges belong aggregately to another; the hills of uplifted Miocene in the Rocky Mountains, another; the Archæan Front Range of the Rocky Mountains, and whatever ridges were one with it in origin, constitute another. The Rocky Mountain mass is a combination of whatever individual ranges occur in it (only those within the limits of the United States being yet studied), and also of the results of a still later mountain-making movement, that of the Tertiary, when the mountain mass was raised as a whole. It is polygenetic.

The *monogenetic* mountain ranges are of the following kinds: first, those consisting of a combination of folded ridges, like the Green Mountains, Appalachians, the Apennines, Carpathians, Coast Ranges of the Pacific Coast; secondly, those made up of one prominent mass, with a granite core along the axis or toward one side, which granite was made in the mountain-making process, as the Sierra Nevada; third, those of more or less upturned strata and extensive outflows of igneous rocks, like the Mesozoic areas of the Atlantic border. All gradations between these three kinds exist. Other more complex structures are polygenetic combinations of two or more of these kinds.

J. D. Whitney states, with regard to the Sierra Nevada, that the granite axis widens southward, and volcanic phenomena increase northward. Granite makes nearly the whole of its mass at the south end, from the Tahichipi Pass almost to Mariposa County; but, north of this, up to American River, its area narrows, it being confined chiefly to the summit and eastern side, the rest of the mountain region consisting of clay-slate, mica and other schists, with quartzytes, serpentine, and some limestone, and some granite in the mica schist; while north of American River the schists constitute nearly the whole breadth, granite occurring only in occasional areas along the crest and east of it; and but little of the granite is gneissoid. Igneous rocks, on the contrary, increase in amount northward. They cover part of the gravel beds in the several counties from Mariposa to Plumas, a large part in Butte and Plumas counties, and almost the whole surface north of Plumas, near whose borders stands Lassen's Peak, an extinct volcanic cone, somewhat above 10,500 feet in height, and from which there is a series of cones, extending northward, that culminates in Mount Shasta. The dip of the schistose rocks is for the most part, according to Whitney, eastward, or toward the granite axis. The range has its greatest height between the parallels of 36° and 37° 10′, where are several peaks over 14,000 feet. The western slope is mostly between 100 and 250 feet to the mile, and the eastern, for a large part, 1,000 feet to the mile. The quartz veins of the schists are the original sources of the gold; and El Dorado, Placer, and Nevada, are the great mining counties. Butte and Plumas afford much less gold, and probably because the surface is so widely covered with igneous rocks.

2. *Continents.* — Continents, in the earliest stage recognized by geology, were great and almost featureless plateaus, separated by depres-

sions, which the presence of water made oceanic areas. Facts prove that they were more or less submerged during the larger part of geological time. But they also announce that the continents and oceans have never changed places; and, on the contrary, that the continental plateaus and the oceanic depressions have always been working in opposite directions. The explorations of the ocean's depths have led Sir Wyville Thomson, the chief explorer of these depths, to the conclusion, long sustained by the author, that the continents have been a gradual growth through successive sedimentary accumulations over *continental*, and not over oceanic seas, and by means of other gradual changes — deep-sea deposits having striking peculiarities not found among the strata of the continents. Moreover he regards it as highly probable that the oceanic depressions have only in comparatively recent times reached a depth, through the progressing changes, which permitted the formation of the *abyssal* beds.

Continents as they now are, in their finished state, instead of being half submerged plateaus, are combinations of two or more polygenetic mountain chains, one on either border, the axis of the chains usually within five hundred miles of the adjoining ocean, and the larger of the mountain chains stands facing the larger of the oceans (p. 23).

But while the extreme stages — the earliest and latest — are so diverse, there is fundamental unity, since the courses of mountain ranges and chains over the continents, and the trends of coast-lines and of oceanic islands, have the same general directions with those of the first incipient emerging land of Archæan time.

3. ORIGIN OF MOUNTAINS, AND OF THE ATTENDANT PHENOMENA.

The sources of the phenomena exhibited in mountain regions are primarily dependent on movements in the earth's crust. But many of them have special causes, which experiment and observation illustrate; and these may be first considered, before proceeding to the part of the subject that is more or less conjectural.

I. Explanations of some of the Subordinate Phenomena of Mountain-making.

The subordinate phenomena here considered are: 1. Flexures; 2. Fractures, Faults, Joints; 3. Earthquakes; 4. The Inequilateral Character of Mountains.

1. Flexures.

1. *Facility of Flexure.* — No material is so solid that, when in broad tabular masses, it will not become flexed by lateral pressure

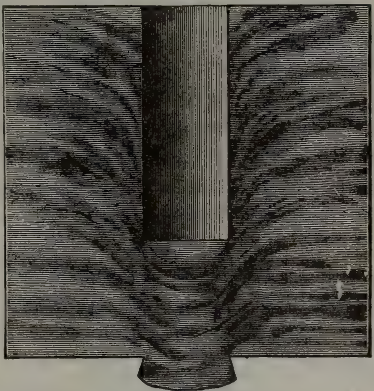
very gradually applied. By "very gradually" should be understood movement by the yard or so a century, or that degree of extreme slowness which has so often been exemplified in geological history, and which is the most common of nature's methods of progress. The rock, or other solid, though apparently inflexible, will undergo, under such conditions, a molecular movement, adapting it to its new condition.

In support of this statement, there are the facts respecting ice, stated on page 695. The bending of great masses by their own weight goes on without any fractures of the stretching side; a movement in the molecules takes place, in which the concave side loses and the convex side gains, so that the density remains throughout the same. There is no reason to doubt that if ice covered a lake to a thickness of a score or more feet, and a slowly-accumulating pressure to a sufficient amount could be brought to bear against one side of it, the ice might be plicated over its surface, as boldly and numerously as the formations of the Appalachians.

This subject is further illustrated by the "flowing of cold metals" when under pressure, first recognized as a principle by Tresca. The pressure, he says, is transmitted from particle to particle through the interior of the mass, and thus tends to produce a flow of metal in the direction of least resistance. In well-conducted experiments at the Stevens Institute, Hoboken, by Mr. David Townsend (published in the Journal of the Franklin Institute for March, 1878), rectangular blocks of iron, accurately planed and measured (being made about 1·75 inches wide and thick, and 2·5 inches long), were punched cold through the centre with a punch 7-16ths of an inch in diameter. The core which came out (Fig. 1152), was only 11-16ths of an inch (instead of 1·75 inches = 28-16ths) long; and yet, like the punched block, it was essentially *unchanged in density*. Mr. Townsend's experiments and measurements show that over two thirds of the metal which had filled the hole had moved off laterally or in the direction

Figs. 1151, 1152.

1151.



1152.

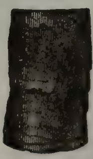


Fig. 1151. Punch at a depth of 1¼ inches. Fig. 1152. Core out.

of the width and length of the block; and this lateral movement or flow had bulged the sides much more at bottom than at top, and most about the middle. At bottom the block was increased 1-25th in width and 1-50th in length. The block had been made of plates of iron welded together, and these were bent downward as the punch passed in, the lower ones the least; and Fig. 1151 shows the appearance of the surface, after polishing and etching it with acids, of a section through the middle, when the punch had entered $1\frac{1}{4}$ inches and the core projected an eighth of an inch. The molecular flow is essentially like that of pitch or any other fluid.

Strata, when they were folded, were generally (1) those of sedimentary formations; (2) only partially consolidated, limestones excepted; (3) containing more or less moisture and having the cohesion diminished thereby; and, (4) as the movement proceeded, they were receiving heat through the friction, which, if low in degree, made siliceous solutions and so further diminished friction; and, if high, produced superheated steam with a general softening of the flexing masses.

2. *Forms of Flexures.* — The flexures undergone by strata are not easily reproduced by experiment in the small way, because the element of weight is one of chief importance. The weight is very great if only 20,000 feet of rock are undergoing flexure together. It influences largely the shapes of flexures, however the disturbing force be applied, and increases the resistance from the underneath terranes that do not participate in the movement.

The contraction of a stretched strip of caoutchouc, overlaid by adhering layers of clay, has been used to exemplify the flexures in the earth's supercrust over the contracting crust. Flexed and steeply upturned beds and gaping fractures are obtained; but the result fails of imitating nature in two respects; (1) the flexures have not the unequal-sided character which pushing from one direction produces; and (2) they are a continuously progressing effect of the contraction, when mountain-making over the earth has occurred at widely separated epochs.

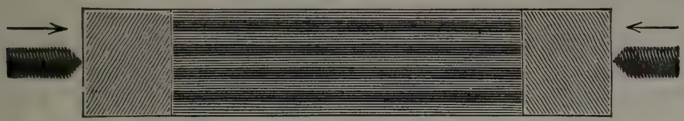
The effects of flexure are modified by differences in the beds as to texture — some being made to break, when others stretch or become compressed; also by inequalities as to amount of moisture and heat present, and in their conductivity of heat — determining differences as to facility of movement.

Shaly or slaty strata, when raised into nearly vertical position, would be liable to have the layers crumpled or finely plaited by simple weight, as well as by the pressure that caused the uplift, while sand-beds might settle without leaving any evidence of it.

2. Fractures, Faults, Joints.

1. *Fractures, Faults.* — The production of fractures through change of temperature, and, especially, cooling, has been briefly treated on page 720. The results of lateral pressure have been experimentally illustrated by Daubrée. In one of his experiments he used an oblong square prism consisting of layers of beeswax, and applied the force at the middle of the two ends, after protecting them by small blocks or

Fig. 1153.



Prism of layers of wax of different colors. (x ½.)

plates of the same cross-section. Fig 1153 represents, half the natural size, the prism ready for the experiment. One of the results,

Fig. 1154.

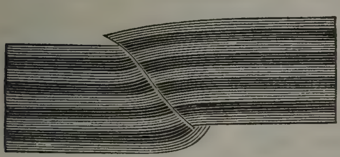
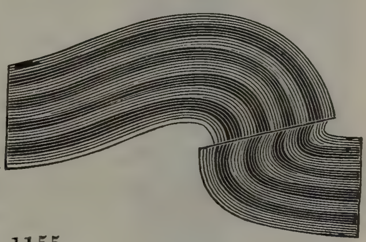


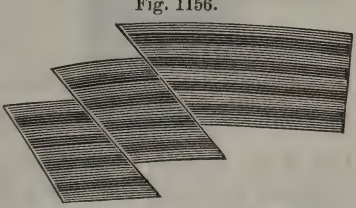
Fig. 1155.



after applying the pressure, is shown in Fig. 1154; and another, after using a stronger pressure, in Fig. 1155.

In both a flexure becomes the course of a fracture and also of a fault. In Fig. 1156 are shown two oblique fractures and faults, obtained in another trial. The fractures have *their planes parallel* as well as oblique; and the faults were made by a *shove up* along the oblique surface. So the greater fractures of mountain regions often have the obliquity (p. 793) as well as parallelism, and sometimes have been

Fig. 1156.



faulted in the same way, though in minor faults the displacements have generally been made by a dropping of the opposite side. The direction of dip of the plane of fracture, as the figures show, is *in the case of a synclinal bend the reverse of that in the anticlinal.*

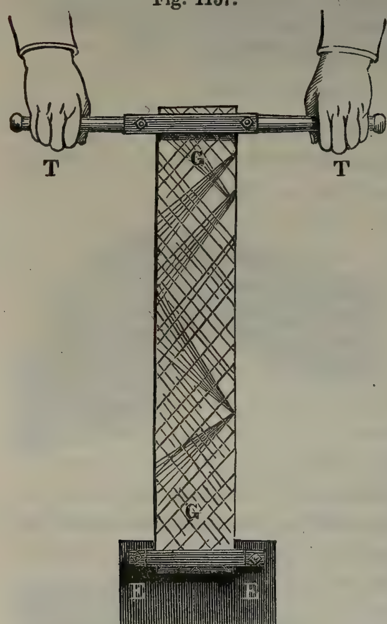
In subjecting to vertical pressure a square block of wax, having a breadth of five and a half inches and a height of about a foot, an oblique diagonal fracture was made with some bulging of the sides; and,

adjoining the fracture, as a consequence of the molecular movements in the bulging, fine rectangular cracks were produced, like a delicate network.

Cubes of hard rock usually break off at the angles and edges, leaving two rounded cones with their tops at the middle; but a tabular block of limestone under vertical pressure was reduced by Daubrée to vertical prisms and plates.

Daubrée has also beautifully illustrated the production of a system of joints by a slight torsion. He subjected plates of ice to this action and obtained, as one of his results, with a plate nearly a yard long, the fractures shown on a much reduced scale in Fig. 1157. Figure 1158 shows a portion of one of the plates one fourth of the natural size. [It is from a photograph, and hence the reflections from the surfaces of fracture give a false appearance of ridges along the fractures.] Daubrée draws attention to (1) the approximate parallelism of the lines, and yet their slight divergence; (2) the crossing of one set of lines by another nearly at right angles, *anti-parallels*, as he calls them; (3) the fact that the lines are in groups; (4) the fact that joints may be an instantaneous effect; (5) the very important fact that the force producing the joints did not act at right angles to either set, but at the extremity of a bisectrix to the angle of intersection of the two sets; and (6) the fact that the slower the action of the force and the larger the plates, the nearer the approach to parallelism between the lines in each set. Other instructive figures are given in his important work on Experimental Geology.

Fig. 1157.



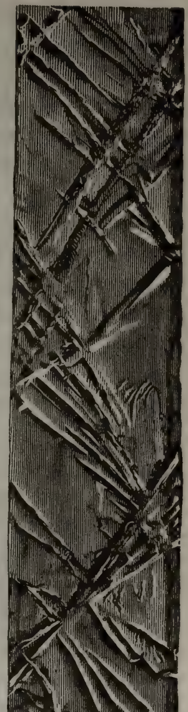
Lines of Fracture in a Plate of Ice produced by slight torsion. ($\times \frac{1}{12}$.)

It is apparent from the statements on page 789 that some amount of torsion has generally taken place in connection with the folding and fracturing of rocks. The lines of trap dikes in the Connecticut valley (map, p. 19), probably owe something to it. It is a consequence of fracturing by torsion that the fractures it produces might be left as

open fractures, when those from direct pressure alone would remain closed.

But in the movements of the rocks torsion has always been feeble compared with the direct action of the fracturing force; and the more feeble the more nearly would one of the sets of fractures be predominant, and have a course at right angles to the action of the force. As a matter of fact, joints are commonly parallel, or nearly so, to the axis of upheaval, or of two or more upheavals, in a region; and they have been made in the course of the same slow movements which made the mountains.

Fig. 1158.



Portion of a plate of ice showing its fractures ($\times \frac{1}{4}$). From a photograph.

The effects of pressure in *breaking and distorting fossils* are also among Daubrée's reproductions of nature's work by her own methods. He has also added to the illustrations of the origin of *slaty cleavage.* It has been recognized by many, since Sedgwick first taught right views respecting the cleavage of slates, that the structure was due to the flattening of compressible grains and air cavities in the clayey material, and the putting into parallel positions all flat particles, through the action of lateral pressure. This view has been sustained by Sorby's microscopic examinations, and his experiments subjecting to pressure clay and scales of oxyd of iron; by Tyndall, who has rendered beeswax, clay, and other substances, laminated by simple pressure; and later by Daubrée, who experimented with clay and scales of mica, and obtained a perfect schistose structure. The rolling and hammering of metals results in a laminated texture, which fracturing or acids may reveal, when not otherwise visible; and several fine examples are figured by Daubrée.

The fractures that have given exit to igneous ejections have often had a width of 200 feet, and sometimes have exceeded this. Such open fractures might be made in anticlinals, but seemingly not in synclinals. A lateral pull rather than a lateral pressure is apparently required for their origin.

The production of oblique planes of fracture, and an eastward dip, in the great north and south Mesozoic dikes of the Connecticut valley accords with the results obtained by Daubrée in a synclinal bend, as exemplified in Fig. 1155, p. 801; but how the many great fissures came to be left open so widely for igneous eruptions needs explanation.

3. Earthquakes.

An earthquake is a vibration within the rocky sides of the earth, begun in some deep-seated region of local disturbance, and propagated upward and outward from that place as a centre. The vibration is a longitudinal wave, like the sound-wave in the atmosphere, but it is varied in its movement by differences in the elasticity of the rocks traversed, and often also by their want of continuity. The disturbances probably come, for the most part, from yielding to a pressure caused by the previous conditions connected with mountain-making in that part of the sphere. They are most likely to be located where there was previous weakness or a course of former fracture. Regions of volcanoes, extinct or active, are also regions of earthquakes; and as these are situated mostly along the borders of the continents, or in and near the great transverse seas dividing the northern and southern continents, so these are the areas that suffer most from shakings.

The observations of Professor W. H. Niles on the gneiss of a quarry at Monson Mass., show that even the solid rocks are in some places under a strain; for he states that bendings, sudden fractures, and expansions of the rock often take place; masses, before their ends are detached, become bent upward at middle; and one mass, three hundred and fifty-four feet long, eleven wide, and three thick, was an inch and a half longer after it was detached than before; showing a strain which was greatest in a direction from north to south — an effect due to compression by the pressure the rocks had been subjected to and a consequent expanding in a transverse direction. All are familiar with the crackling sounds occurring at intervals in a board floor of a house, and arising from change of temperature, especially in a room in winter that is heated only during the day; and with the more common sounds of similar character from the jointed metallic pipe of a stove or furnace, given out after a fire is first made, or during its decline. In each case, there is a pressure or tension, accumulating for a while from contraction or expansion, which relieves itself, finally, by a movement or slip at some point, though too slight a one to be perceived; and the action and effects are quite analogous to those connected with the lighter kind of earthquakes.

There are other causes for local shakings, among which are — the undermining of strata; the sudden evolution of vapors about volcanoes; and local changes of temperature in the crust; but these are of minor importance.

Tidal waves in the internal igneous material of the globe have been considered a chief cause of earthquakes. Investigations carried on by Alexis Perrey, of Dijon, France, have seemed to indicate that there is a periodicity in earthquakes, synchronous with that in the tides of the ocean, — the greatest number occurring at the season of the syzygies, in each lunar month. If the earth has not very free liquidity within, some other explanation of the facts, so laboriously worked out by Professor Perrey, will have to be found.

The sudden fracture or displacement causing an earthquake produces a small longitudinal oscillation in the rock particles, the amplitude of which may not exceed a few inches, or even one inch. But the wave-motion thus engendered travels to great distances; and it has a velocity generally of about 20 miles a minute, while that of the oscillating rock-molecules is very much less.

By ascertaining, through observations on the earthquake vibration and its effects, the direction of the longitudinal wave along any two lines over the earth's surface, the courses of the radii from the centre of the region of disturbance are readily obtained; and their intersection will give the position of this central region, situated directly over the centre of propagation. Further, when the position of this central region has been obtained, the angle at which a wave-path reaches the surface, if an oblique angle, affords the means of determining the depth of the seat of disturbance or the seismic centre; for the larger this angle the greater the depth of the seismic centre below the centre of surface disturbance. Since the seismic centre may be a region miles in breadth or length, the centre at surface may also be large; and owing to this cause, and variations in the nature and condition of the vibrating rocks, the *coseismic curves*, or lines along which the wave-paths reach the surface at equal angles and cause simultaneous earthquake effects, cannot be concentric circles. *Isoseismic* curves are those along which the destructive effects are about equal. The overthrowing of objects is greatest outside of the central region, because an oblique thrust is more effective in this respect than a vertical one.

The observations made by seismometers aim to determine the direction, intensity, and velocity of the wave at different points over the disturbed region. The directions of fractures made in walls or buildings are an important means of ascertaining the direction of the wave-path as it emerges at the place, and the positions of overturned or displaced objects are an important source of information.

Mr. Robert Mallet, by whose researches and labors the science of seismology was largely developed, determined, in his study of the Neapolitan earthquake of 1857, the wave-paths at twenty-six stations around the seismic vertical, and obtained for the mean depth of the seismic centre about 5¾ geographical miles. The amplitude of the rock vibrations causing the wave was determined by Mallet to have not exceeded 2½ inches; and this movement traveled in the rocks at a rate not over 15 feet per second. This velocity, although very much less than that of the propagated wave (the mean for which in the Neapolitan earthquake was found to be 788 feet per second), is the chief source of catastrophe in earthquakes. Mallet deduced from Humboldt's account of the earthquake at Riobamba in 1797 (when the bodies of some of the people were thrown across a river, to a height of 100 feet), that the velocity of the wave was at least 80 feet a second, and that the depth of the siesmic centre was 30·64 geographical miles, or not far, in his view, from the greatest possible depth. Dr. Oldham found for the depth of the centre in the earthquake of Jan-

uary, 1869, in Cachar, India, about 30 miles. Lasaulx determined for the same in the case of an earthquake near Aix-la-Chapelle (Aachen) in June, 1877, about 16·85 miles; and for that of another in the same region in 1873, a position toward the base of the supercrust (p. 147); but his results have been questioned.

The noted earthquake of Calabria commenced its shocks in 1783, and continued them to the close of 1786; 949 were counted in 1783, and 151 in the following year, more than half of which were of great violence; they were felt through Sicily and as far north as Naples, but the region over which they "excited intense alarm did not generally exceed 500 square miles in area."

Henry D. Rogers, many years since, showed that the earthquake of the 4th of January, 1843, traversed the United States from its northwestern military posts, beyond the Mississippi, to Georgia and South Carolina, along an east-southeast course, Natchez lying on the southern border, and Iowa about the northern; and made out for the rate of travel, thirty-two to thirty-four miles a minute.

The principal geological effects of modern earthquakes come through the forced or translation waves they make in the ocean, as explained on page 679. The minor effects are: (1) the displacement of loose rocks; (2) destruction of life in the sea, on the same principle that a blow on the ice of a pond will stun or kill the fish in the waters beneath; (3) destruction of life on the land. Destruction of cities and of human life have been too often recounted to need special illustration in this place. The great fractures and the changes of level often connected with them have a place, for the most part, among causes rather than effects. In times of mountain-making, when faults thousands of feet in depth were made, each at successive shoves, if not abruptly, the destruction to life may have been almost world-wide. The waves made in the air, or sound-waves, are part of the sensational effects of earthquakes.

The great depth of some earthquake centres favors the conclusion that the earth's volcanic and mountain-making operations have ordinarily affected subterranean regions far below the limit of the supercrust.

4. Inequilateral Character of Mountains.

The succession of flexures which make up some mountain ranges, from one side to the other, are evidence that the force producing the upturning *acted laterally*.

The additional fact that these flexures, as a general thing, have, in mountains like the Appalachians, an *inequilateral* character, with the steeper slopes facing the same way (p. 788), proves that the lateral

pressure acted *unequally from the two opposite directions;* that there was a *shoving side* and a side of greatest *resistance.* Further, the mountain range, as a whole, has often the same inequilateral character, — that is, it has steep, numerous, and close-pressed folds on one side, with frequently abundant metamorphic action as evidence of the heat produced, and, on the opposite, a falling off into gentle swells, with little or no results traceable to heat beyond some solidification.

This front-and-rear feature, in the mountain range as a whole, and also in its subordinate parts, could not have come from any force acting from beneath the region, causing folds either side through a reflex action, for the folds should then have had reversed forms on opposite sides of the range. It must have been made through a side-push, through a shove from one direction — that facing the steepest and most numerous folds — and resistance, or a less movement, on the opposite side. In the case of the Green Mountains, the position of the unyielding or resisting mass behind is manifest; for there, through all the progress, stood the Archæan rocks of the Adirondacks and Canada. This front-and-rear feature is common throughout the globe. It is expressed in the Andes, the Sierra Nevada, the Rocky Mountains as a whole, and not less in the mountain regions of the Old World.

Professor Suess, of Vienna, speaking of the Alps, says that a glance at the position of the crystalline rocks of the Finsteraarhorn overlying the younger strata, shows that the folding over must have originated, not in the eruption or expansion of isolated central masses, but in some general horizontal movement of the mountain-system, as a whole. He states that it is also apparent from the unequal-sided folds in these Alps, and in the subordinate ranges of the Apennines, Carpathians, and Jura Mountains, that there was a shoving side to each in the making of the mountains. He speaks of the "whole Jura Mountains pressed up into many parallel bands," while, to the west, "the Jurassic deposits, covering a wide area show no trace of this tremendous horizontal movement;" and of the "horizontal shove" from one side by which the Apennines were made.

5. General Conclusion from ascertained Facts as to the Mountain-making Force.

The preceding review of ascertained facts leads to the following deduction: That the force making slaty cleavage acted laterally; that the fractures and joints in rocks are best explained, for the most part, by reference to the same mode of action; and that flexures and other features of strata, and the features of mountains, indicate not only that the action was lateral, but, also, that it was not equal on the opposite sides of the mountain-making region; in a word, that *the or-*

ganizing force was lateral pressure or thrust; and that there was *a pressing side*, and a more feebly pressing, or virtually *resisting side.*

II. Fundamental Agency in Mountain-making.

The organizing force in the sphere having acted by *lateral pressure* or thrust, what now is the source of this pressure? What condition in the earth's interior has caused that lateral pressure should have been evolving effects through all past time; should have worked out the earth's grander features, making even its mountain chains? The answer to this question involves a consideration of the nature of the earth's interior; this done, we are prepared to consider the working methods of the force engaged, and the special steps in the making of mountains and continents.

1. Condition of the Earth's Interior.

Three opinions respecting the earth's interior have prominence: *First*, that it is wholly solid to the centre; *secondly*, that it has a solid centre and crust, and a liquid or pasty layer between; *thirdly*, that it has a solid crust and liquid interior — the interior either perfectly liquid; or wholly in a pasty state; or pasty above and liquid below.

Arguments on the subject have been based on the following considerations: —

1. Considerations connected with the Attraction of the Earth by the Sun and Moon. — (1.) The precession of the equinoxes is due to the attraction of the sun and moon on the protuberant equatorial portion of the globe; none would exist were it a perfect sphere. Professor W. Hopkins sought to ascertain the difference between the present amount of precession and what it should be were the interior a liquid moving freely beneath a thin crust. In such a case the force producing the precession would not have to pull around the liquid interior portion, on account of its (assumed) freedom of movement, and the precession should therefore be greater than with a solid globe. Finding, by his calculations on the basis of a solid or nearly solid globe, that the precession obtained agreed quite closely with the existing amount, Professor Hopkins concluded that the solid crust must have a thickness of at least 800 or 1,000 miles.

But, as pointed out by Hennessy, and later by Delaunay, the assumption by Professor Hopkins of a condition of perfect freedom of movement in the liquid of the interior is unwarranted. For all liquids move with some friction among the particles, and the most liquid of lavas, with a very large amount of it; and if there was a pasty state for a considerable depth beneath the crust, so that, for a

thousand miles, this viscid portion would move with the crust, the case would meet the conditions required by Professor Hopkins's calculations.

(2.) As the attraction of the sun and moon causes tides in the oceans, so if the earth has, beneath a thin crust, a perfectly free-moving liquid, this interior liquid, as has been often urged, might have its tides. Sir W. Thomson has investigated mathematically the amount of deformation the earth would thus undergo, and its effect on the height of the oceanic tides, *assuming* an *elastic shell*, and an *incompressible fluid* of perfect liquidity within, as the basis of his calculations; and he reached the conclusion that if the globe were as rigid as glass, it would still yield enough to reduce the tides to three fifths the height they would have if it were absolutely rigid, and to two thirds, if as rigid as steel. Precise observations for a comparison of the results of calculations with facts, he says, cannot be made, because, especially, of the influence on the tides of the distribution of the land. But he concluded that 2,000 to 2,500 miles is the least thickness of crust that would withstand the distorting action. Sir W. Thomson deduced a like conclusion from the amount of precession and nutation.

This argument, as Professor Hennessy states, is open to the same kind of objection as the former; and he says further, that an elastic shell and an incompressible fluid are wholly imaginary, since the shell is not elastic and a fluid is never incompressible; and that, as Laplace pointed out, part of the work done in a compressible fluid would be the causing of variations in density. Recently (in an Address at the Glasgow meeting of the British Association in 1876), Sir Wm. Thomson has acknowledged the invalidity of his arguments from the precession and nutation, and has virtually admitted the force of these objections.

2. Considerations connected with Solidification.— (1.) Since (*a*) the pressure increases in a liquid globe from the surface to the centre, and augments more or less the density below, and (*b*) pressure raises the fusing point of most substances, it has been argued that consolidation must have begun at the centre. But the heat may so increase from the surface to the centre as to neutralize any tendency to solidification from pressure. And, again, the effect of pressure on the fusing point may have its limit. The fusing point of sulphur, which at the ordinary pressure is 225° F., is raised, according to Hopkins, by 7,790 pounds of pressure to the square inch, to 275½° F., and by 11,880 pounds, to 285° F., — showing an increasing rise with the pressure. But these numbers indicate, as Mr. David Forbes has remarked, that the effect in raising the fusing point diminishes greatly with the pressure, it taking on an average three times more pressure between

7,790 pounds and 11,880 pounds to raise the fusing point one degree than it does below 7,790 pounds, and hence they sustain, as he has urged, the idea of such a limit.

(2.) Again, it has been argued that since hardened rock is denser than fused, and, therefore, any portion that became solid at surface with the progress of cooling would sink and be refused; that this process would continue until the whole interior, to the very centre, was too stiffly viscid or pasty to allow of further sinking; and only then would a permanent crust begin to form.

But, as Professor Hennessy observes, the materials in fusion would arrange themselves in strata according to their different degrees of density, and hence, in the progressing solidification, the hardened rock would sink only to a limited distance beneath the surface, and the circulation would be comparatively superficial; that thus a crust would finally be formed with a pasty layer or region beneath it, and below this there might be complete fusion to the centre. Mallet sustains the same conclusion on the ground that slags form over a fused mass of the slag-material at a temperature very near that of fusion. Muirhead, in his experiments with reference to the point here considered, found that when a bar of cold iron was dropped endwise on fused iron, it bounded back to the surface, and melted there; and that when masses of trap (whinstone), and also of cold furnace slag, of five or six pounds weight, were placed on fused slag, they at first sank, but soon came to the surface and floated about until they were melted. Further, owing to escaping vapors attending the igneous fusion, the first cooled material would be light from air-vesicles, like scoriaceous lava.

It is also an important consideration that the study of meteorites has led some astronomers and writers on the subject to the opinion, in view of the iron in these bodies, and of the fact that their place in the solar system is to a large extent near that of the earth, that the earth's interior consists, for the greater part, of iron. This view is favored, also, by the high percentage (10 to 14) of iron oxyd in most igneous rocks; the existence of much native iron in doleryte at a locality in Greenland; and the occurrence of the greatest of iron ore beds of the world in the oldest rocks, the Archæan. Platinum, gold, silver, and copper are heavier metals; but it is remarkable that they are not brought up among the constituents of eruptive rocks, as iron is, but are obtained from the supercrust and its veins: as if these metals, in consequence of being in vaporizable combinations, or those of comparatively little specific gravity, were near the surface of the fused globe, while below these were the iron and what, under the conditions, could form alloys with it. If the earth is two thirds iron, or iron to within 500 miles of the surface (without much increase in the density of the iron downward), and the rest were made of dolerytic material, it would have about its present specific gravity, 5·5–6. With such a nucleus, the stony material, made as cooling went on at surface, could not sink down into the iron; and not to it, because of the density of an overlying region. Whether the iron would be in a solid state or a liquid, science may yet determine.

3. The demands of Geological Facts. — Geological facts relate to the crust and supercrust, and do not touch the question as to the earth's

solidity at centre. They demand that the crust, or the exterior, should have freedom to change its surface-level through the action of forces within or beneath it; that the general refrigeration which has taken place should have left the sphere with a sufficiently flexible crust, or movable or expanding exterior, to allow of all the elevations and depressions which geology makes known.

If the crust is of such a nature and so thin as to admit of a slight degree of warping, geology has then a basis for explaining the great Pacific Coral Island subsidence of the Quaternary; the slowly progressing subsidence of the Appalachian region, taking all of Paleozoic time to bring it to an end and a crisis; the high-latitude subsidence during the era of melting of the great glacier, or in the Champlain period; the geanticlinal or upward movement, which raised the Rocky Mountain region, or portions of it, over 10,000 feet since the Cretaceous period, and made like movements over other continents; the high-latitude elevation which brought the continents up to their present level after the Champlain period of the Quaternary. Again, the folds and upturnings accompanying mountain-making, as illustrated in the Appalachians, Juras, Alps, and other ranges, show that they were made by a lateral shoving of the beds; and lateral thrust is one of the certain results from such conditions. Moreover, they were made simultaneously over regions covering many thousands of square miles; and action on so grand a scale also would be a necessary consequence. Connected with such foldings and upturnings, there have been great fractures, and faults of 10,000 to 20,000 feet; and there also would be other natural results. Further, the increasing temperature of the earth's crust downward (p. 717), and the very wide distribution of volcanoes and regions of igneous ejections over the globe all harmonize with the idea of a thin crust.

If, on the contrary, the crust is not thin enough to make the geosynclinals and geanticlinals, which facts prove to have taken place, appeals have to be made to other conditions; and the more reasonable of those hitherto presented are the following: —

1. Change in the *temperature* of great regions beneath the crust, producing expansion and rise with its increase, and contraction and subsidence with its decrease.

But movements in heat could not take place without an adequate cause, and they are not shown to be a possibility. They are far less explicable in a globe having a rigid crust than in one having a thin crust over a liquid or plastic interior.

In the case of the Appalachian geosynclinal, the trough became filled with sedimentary beds as the subsidence went forward, and attained at last a depth of 30,000 or 40,000 feet; and it has been supposed that the heating up of the bottom beds (as explained on page 718) may have caused their expansion, and thus produced the folds and flexures now observed in the rocks. But this expansion, and therefore the folding, should have gone on cotemporaneously with the deposition, or with its later part at least. Far from this, there is conformability from the bottom to the top. It has been said that this heating from below might tend to raise the surface, and be a cause of oscillations of level; but in the case of such geosynclinals, the subsidence in progress overbalanced action of this kind if any took place.

The expansive force of moisture gaining access to such beds has been appealed to as a cause of elevation and flexures. But such sedimentary beds contain their maximum of moisture when formed; and with this, although situated at the bottom of the trough, they have still laid quietly as to any folding (not, it may be, as to consolidation) until the epoch of mountain-making has finally come; and in the mean time the effect from any expansion did not prevent progress in the subsidence.

With a rigid globe, the source and extent of volcanic and other igneous action are insufficiently explained. For the sake of an explanation, the solid interior has been assumed to be just at the verge of fusion; and areas of liquidity have been supposed to come from a sudden diminution of pressure, on the principle that pressure modifies the fusing limit (p. 809). But how such a diminution could have been produced for the multitudes of cases of igneous eruptions over the globe, along lines often a thousand miles or more in extent, is not satisfactorily explained. It has been supposed that mountain lifting may sometimes make open spaces below; but no method in a rigid globe could do this, unless expanding vapors were indefinite in supply for the purpose, and hardly then; and open spaces so made could not remain such. Erosion over the surface has been urged as a cause, but this, at its most rapid rate, tends only to lower the isogeothermal planes just as the accumulation of beds raises them (p. 718).

Further, the great faults in the rocks have no adequate explanation on the view of a very thick rigid crust or a rigid globe; for there could be no faulting in such a globe below the limit of the supercrust, unless from the improbable condition of an unequal heating of the two sides; and there could be likewise no friction or crushing to make the heat of fusion.

Among geological facts, none appears to demand for its explanation a rigid globe. The demand has come through the supposed requirements of physical laws, studied with the aid of the highest mathematics, whose methods and conclusions are sure only when all the modifying conditions of the problem are thoroughly understood. It is now admitted by some of the best of physicists that no arguments have yet been presented which prove the earth to be a rigid globe, or to have a rigid crust a thousand miles or so thick; and it is also admitted by some mathematicians and physicists of eminence, including Airy, the Astronomer Royal, that the hypothesis of a thin crust over a liquid interior is probably the true one.

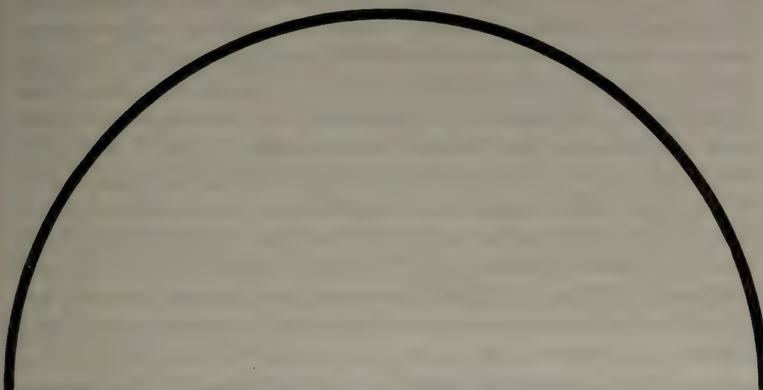
The Science of Geology is, therefore, free to adopt the conclusion which seems best to suit known facts.

2. The Force engaged in Mountain-making.

The present actual thickness of the earth's crust, or that at any particular period in the past, may always remain unknown. All that geology can claim to teach is that it is thin enough to undergo some change of level through the forces within or beneath it. That the reader may better appreciate the problem, a cut is here introduced (Fig. 1159) representing a section of a hemisphere, supposing the crust only *one hundred miles* thick — that is, a fortieth of the radius. In the cut

the radius is two inches, and the crust *one twentieth* of an inch. It is well for those reading on the subject of the making of mountains to put the fact in mind that an elevation on the earth of *five miles*, or

Fig. 1159.



26,400 feet, would correspond in this section to a *four-hundredth* of an inch, or to but twice this, if the height is measured from the bottom of an ocean five miles deep.

1. Working Agencies. — Owing to the circumstances attending the original solidification at surface, causing a gradual cooling down of the liquid material to a considerable depth, there is probably a densely viscid or pasty region, of great thickness, beneath the crust. In such a globe undergoing continued refrigeration, the causes of mechanical action are chiefly the following: (1) Gravity; (2) Vapors rising from the viscid material; (3) Lateral pressure or tangential thrust of the crust, due to the contraction beneath and against it.

1. *Gravity.* — In a globe of the size of the earth with a thin crust, the weight of the crust is not sustained, in the opinion of physicists, by its arched condition. It was hence suggested by Herschel that an accumulation of sedimentary beds to a great thickness over large areas might be accompanied by a gradual sinking of the crust; and a sinking equal in depth to the accumulation, and concurrent with it, has been assumed by some writers. But this latter effect could be produced only on the condition that the liquid beneath the crust is a fluid with little friction between its particles; and but slight effect would result if it were densely viscid.

With regard to the power of the crust to sustain weights laid upon it, facts are afforded by the existence of lofty mountains in spite of the yielding conditions underneath. By or before the close of the ear-

liest of the ages, the Archæan, mountains were raised to a height of many thousands of feet and left standing on sure foundations. Great subsidences had previously taken place; accumulations of Archæan sedimentary beds, a score or more of thousands of feet in thickness, had been laid down; and, finally, the mountains were formed out of the sedimentary beds, and made to stand high and firm. The Adirondacks, for example, were certainly 5,000 feet (*plus* what has been lost during subsequent ages through denudation) above the level of the sea-beaches of the Potsdam or Primordial era, the first period of the Lower Silurian, for the Potsdam sandstone was in part a beach deposit; and they continued to stand aloft, with small changes of level, during all the long Paleozoic periods, when the crust of the Appalachian region, to the south, was slowly subsiding. And they have stood there ever since (besides other Archæan heights to the south and southwest, and those of North Carolina of even greater altitude) because the crust was able to support them; which capability was owing either to some virtue in the arching of the crust in that part, or to the nature of the crust, or the degree of viscidity below it. The average specific gravity of the Adirondack rocks is probably a tenth greater than that of the Paleozoic sediments of the Appalachian area. Hence the crust could hold up mountains in the earlier as well as later ages.

2. *Expansive Force of Vapors proceeding from the viscid material beneath the Crust.* — Such vapors would act upward, and the result would be simply a bulging of the surface, with the opposite effect, possibly, on their condensation. But if a real cause, these vapors should have been most abundant and energetic early in the earth's history. The fact that the great mountains of the globe received the larger part of their altitude after the Cretaceous period, and hence near the end of geological time, and that volcanoes reached their maximum at the same time, is quite strong evidence that the interior liquid of the globe had lost nearly all that was vaporizable, under the existing conditions of heat and pressure, before the earth was firmly crusted over.

3. *Lateral Pressure within the Crust from Contraction of the cooling viscid layer beneath.* — This contraction of the cooling underlying layer would result either in one or all of the following results: (1) in breaking the continuity of the layer itself, and producing rents opening downward; (2) in making open spaces between it and the crust; (3) in forcing the hard crust above, if adhering to it, to become accommodated to its own decreasing size. Owing to the second of the results of contraction here mentioned, gravity, or the weight of the crust, would produce in it lateral or tangential pressure, with its consequences; and the third would add more or less to this pressure.

Mr. G. H. Darwin, by using an equation for the cooling of "a solid extending to infinity in all directions, on the supposition that at an initial epoch the temperature has had two different constant values on the two sides of a certain infinite plane," deduced by Sir W. Thomson in his paper on the Secular Cooling of the Earth, arrives at the conclusion (see Nature for February 6, and American Journal of Science, April, 1879) that the seat of the maximum rate of cooling moves inward as the time increases; and that the equation, $x^2 = 800t$, expresses the thickness (x) of the crust in feet in terms of the time (t) of cooling in years; so that "if the time which has elapsed from the initial state be 200,000,000 years, $x = 400,000$ feet, or a little less than eighty miles." He adds: "Sir W. Thomson shows in his paper on the Secular Cooling of the Earth, that the solution of his ideal problem will be very nearly correct for the case of the earth, which is supposed to be a hot sphere cooling by radiation. It follows, therefore, from the numerical result which is given above, that the seat of the maximum ratio of cooling must probably be something like one hundred miles below the earth's surface. It does not of course necessarily follow that the seat of the maximum rate of contraction of volume should be identical with that of the maximum rate of cooling; yet it seems probable that it would not be very far removed from it. The Rev. O. Fisher very justly remarks that the more rapid contraction of the internal than the external strata would cause a wrinkling of the surface, although he does not admit that this can be the sole cause of geological distortion. Does it not seem possible that Mr. Fisher may have underestimated the contractibility of rock in cooling, and that this is the sole cause of geological contortion?"

2. **Modifying Conditions.** — Were the conditions of the globe strictly equable in all respects there could have been no continents. The circumstances which modified the action in progress include the following: —

(1.) *The Earth's Rotation:* Producing (a) a bulging over the equatorial regions of the surface-layer, and, to a less degree, of all the concentric beds of increasing density beneath it; (b) through the earth's relation to the sun, a decreasing surface temperature from the equator to the poles, becoming pronounced as solidification went forward; and (c), through relations to the sun and moon, tidal waves moving westward, as long as the degree of liquidity was such as to admit of it.

But the above-mentioned modifying circumstances, although differentiating in their action, could not alone have led to the making of continents. There must have existed, also, for this result —

(2.) *Differences between great areas in the Constitution of the Earth's Material.* — The fact that the continental and oceanic areas were defined in the first cooling of the globe, signifies that in the cooling, or the radiation of heat into space, there were areas of greatest and least contraction.

This difference in cooling and in the resulting level of the surface must have been owing to some difference of quality or condition in the material. One quality has been brought to light by pendulum experiments in India, which, if general for the globe, as has been supposed, is of great significance in this connection, namely: that, without exception, gravity is greater at the coast stations where observations were made than at the continental stations, and greater at the island

stations than at the coast stations. This difference in gravity between continental and oceanic portions of the globe means difference in density.

As the plumb-line is made to deviate from a perpendicular by inequalities of mass in the country around, — arising from ridges and depressions, and from differences in density in the material of the earth whether the surface be even or not, — so the mobile oceanic waters are drawn aside, and, consequently, have a higher level on a mountainous coast than they would have on the same coast if it were backed by a low and level country. Archdeacon Pratt, in his work on the Figure of the Earth, thence derives the conclusion that the position of the earth's oceans is evidence as to the greater density of the rocky material underlying the oceanic areas, and, hence, that the waters have their distribution largely determined by gravity underneath.

The difference in density in the common rocks of the globe is due chiefly to the amount of iron present. If, then, the oceanic crust abounds most in the heavier (it may be basic) rocks, in which iron minerals carry up the specific gravity nearly to or above 3·0, and the continental part most in the feldspathic (chiefly orthoclase) kinds containing less iron, some of the difference of density is explained, and also the difference in fusibility (p. 743); and the same condition accords with the idea that the oceanic areas continued in fusion for a time after the continental, or less fusible, areas had become solid. It is consonant with this that feldspathic (orthoclase) lavas, trachytes, etc., are more abundant in continental regions of igneous ejections than in oceanic.

The globe, when its continental area had become in the main *terra firma*, may hence have had other great areas unsolidified. In that case the surface of the former would at first have been, owing to gravity, nearly on the same level with that of the latter; but as the latter solidified they would have become depressed in surface through the contraction attending the cooling (which amounts in basalt to about eight per cent.); and thus *oceanic depressions* and *continental plateaus* would have been initiated. Moreover, the depressions in this way begun would have gathered in the chief part of the waters of the globe, as they became condensed with the progress of the earth's cooling; and the heat taken up by the waters would have hastened the cooling of the areas, and so aided in the deepening process. The continuation of the contraction through ages since may account for the greater part of the difference which now exists between the depressions and plateaus *in mean level.*

The difference between great areas in the constitution of the earth's material not only localized areas of cooling, but, in consequence of this, determined also differences of direction in the lateral thrust from contraction, and fixed the positions of the areas of least movement or virtual resistance. And it made those conditions permanent for all time; so that oscillations of level took place and mountains came forth, in subsequent eras, parallel to the primal lines of the Archæan age.

III. Mode of Working and the Effects.

The chief effects of the lateral pressure which contraction from cooling has generated are, as already explained, in part, (1) Flexures

of the crust, causing oscillations of level; (2) Fractures; (3) the Evolving of Mountains and the attendant phenomena; and, (4) as a final result, the Evolution of the Earth's fundamental features.

1. Flexures and Fractures.

Flexure implies both upward and downward bendings, geanticlinal and geosynclinal, the one a complement to the other. Such bendings in the crust may have had a breadth of hundreds of miles, but not of one mile, or twenty. If pushed into vertical folds, — that is, folds having the opposite sides parallel, like many in the earth's strata, supposing this a possibility, — the breadth could not be less than twice the thickness of the crust, which would be 400 miles for a crust 200 miles thick, or 50 for a thickness of 25 miles.

Such flexures are little like those of mountain regions; for these are foldings of the supercrust, and have seldom a span of thirty miles; rarely even twenty miles, and generally between one mile and ten, though often less than one. The wrinkles of the contracting globe have been compared to those over the surface of a drying apple; they are related in a general way as to cause; but otherwise, the comparison fails.

The flexures of the earth's crust were, for the most part, oscillations in level of but a few scores or hundreds of feet, the upward movement being often followed by as slight a reverse movement. On page 783 the fact that such oscillations occurred through all the successive geological periods is illustrated by a reference to the Coal-formation.

By causing variations of depth in the continental seas, such oscillations have led to variations in the flow, volume, and positions of currents; in the kind and the quantity, therefore, of detritus which the waters carried, or their freedom from any; in the positions of coast lines and of areas of marine depositions; and thus they have determined variations also in the succession of rocks from sandstone to shale, or conglomerate, or limestone, or the reverse, and in the areas they were made to cover, such as geologists have found in all the formations.

The axis of these oscillations must have been at right angles to the directions of pressure. The directions which the conditions of the earth's crust were calculated to produce were manifested, as has been stated above, in the production of the outlines and mountain courses of the Archæan land; and these — which it is not necessary here to review — were also, therefore, the later courses. They were not necessarily straight lines, since the earth's surface would naturally have had its large elliptical areas acting more or less independently.

A second result from the force at work was the determining of

fractures of the crust, with *friction*, and perhaps, also, *crushing*, along the fractures. The direction of the fractures, according to physical laws, should have been primarily at right angles to the lateral thrust, with sometimes a secondary transverse system. Fractures so produced should also have followed, according to the experiments of Daubrée, oblique planes; and this is the fact with the greater fractures of the crust in mountain-making (p. 803).

2. Formation of Mountains and Mountain Systems.

A monogenetic mountain, as has been explained, comprises all the associated elevations that were made in one mountain-making process, and a polygenetic mountain, those of two or more epochs of disturbance combined into a single mountain system. The former may be (1) a single elevation; or (2) a combination of them making a mountain *range;* and the latter may be a combination of ranges having in general a similar course, and making a mountain *chain* or *system.*

The following are three ways in which a mountain of one genetic process may have been formed: (1) Through a simple geanticlinal or upward bend of the earth's crust; (2) through a simple fracture of the crust, and an upward push or shove along the fracture; (3) through the slow progress of a geosynclinal, and of sedimentary depositions within its area, ending in fracture. The methods by vapors underneath, and by change of temperature, are already remarked upon on pages 814 and 811.

1. Through a Simple Geanticlinal.

Geanticlinals or upward flexures in the crust that became permanent elevations in early geological times are rarely to be distinguished. The region of the Cincinnati uplift may be one of them, as explained on page 217. The time of origin was the close of the Lower Silurian.

Late in geological time, when the crust had thickened much, such movements often resulted in permanent elevations, and many mountains of the world — the Rocky Mountains, for example — owe half or more of their elevation above the sea level to geanticlinal movements; but in all such cases, as far as known, the process was subsequent to other mountain-making action, and perhaps to various epochs of it; so that the regions that were thus elevated may not be examples of the simple monogenetic kind.

2. Through a Simple Fracture of the Crust.

Cases of uplift along great fractures that are not subordinate to other more comprehensive mountain-making work in the region are not often distinguishable. When the plane of such a fracture is

oblique, a monoclinal uplift might be produced by shoving along it. An incipient geanticlinal might be the first step toward such a fracture, according with Daubrée's illustrations (Fig. 1155) on page 801. The volcanoes on the borders of the Pacific, and in other regions, stand on lines of great fractures; but evidence that elevations of the earth's crust were made along them at the time of disturbance cannot often be made out.

Further: the pressure either side of such a fracture might cause elevation along it through the uplifting action of liquid or plastic material thus forced up from below; a result that has often attended ejections on a large scale. (Page 747.)

3. Through the Slow Progress of a Geosynclinal and of Sedimentary Formations within it, ending in Fracture.

From the facts which have been presented and partly recapitulated on pages 785–807, and general facts and principles connected with the physics of the globe, the following are the probable steps of progress in this kind of mountain-making, of which the Appalachians are a good example.

1. *Steps of Progress.* — (1.) As a preparatory step, a geosynclinal gradually deepens through a very long era, over a region of great extent, not much below the sea level; and, concurrently, at equal rate, or nearly, depositions of sediments take place in it, and thus make a great pile of material for the future mountain structure.

(2.) The making of such a geosynclinal, or downward flexure of the crust, presupposes the making of a geanticlinal, or upward flexure on one side or the other, or on both sides, since the two kinds of flexures are complements of one another in the results of lateral pressure. The former would displace, as it descended, some mobile material of the earth's interior, which would go to fill the space made beneath the latter. Facts appear to show that such a geanticlinal existed to the east, but not to the west; and this accords with the fact, elsewhere established, that the lateral pressure acted unequally from the two opposite directions, the oceanic and continental, or had its shoving side and its virtually resisting side.

On the *east* side of the Appalachian trough the coast region was more elevated than now, not only through the Carboniferous, but also through the following Triassic and Jurassic periods, so that the coast-line was far outside of its present limit; for no beds of these eras containing marine fossils occur along eastern Pennsylvania or to the northeast. There is reason for concluding that the barrier existed also in the Trenton period; for, while in the earlier Lower Silurian the life of the eastern border was, in some points, like that of Europe, this was hardly at all so then. Gravity is against the permanence of such upward flexures, and it may be for this reason, and because there was a relief for the pressure in some other direction, that this geanticlinal disappeared. In Cretaceous times the present sea-shore region was replete with life.

On the *west* side of the Appalachian geosynclinal no similar geanticlinal was formed in the Paleozoic era; for marine fossilliferous beds were in progress there, in alternation with peat-beds for coal-making, all through the Carboniferous period.

These conditions just stated involve the following successive steps in the mountain-making process: —

(3.) The bottom of the geosynclinal becomes weakened by the heat rising into it from below. The accumulation of sedimentary beds would occasion, as Babbage long since urged, a rising of heat from below, so that, with 40,000 feet of such accumulations, a given isogeothermal plane would have been raised, neglecting secular cooling, about 40,000 feet. Under such an accession of heat, the bottom of the trough would have been, as Herschel recognized, greatly weakened, if not partly melted off.

The heat in the lower part of the trough is only slightly increased, if at all, by the transformation of motion into heat. The heat thus derived would be feeble in amount if the motion were extremely slow and regular. With fractures, shovings, and crushing accompanying it, the heat from the rise of the isogeothermal might have been much reënforced; but proof that such fractures, shovings, and crushings have occurred before the final catastrophe, usually fails. In the Wahsatch trough the beds at the bottom of the 60,000 feet still have their fossils distinct, or show only slight evidences of change. (King.)

(4.) The weakened trough yields before the pressure, in a fracture of the trough below, and some pressing together of the stratified beds within it. And with this break the shaping of the mountain begins.

Herschel, in a letter addressed to Lyell, dated February, 1836, and in another to Murchison, dated November, 1836, which are published in the Appendix to Babbage's "Ninth Bridgewater Treatise" (1837), presents the view that heat will rise from below into an accumulating series of strata, as had been done by Babbage, and also the hypothesis that subsidence of the earth's crust will be a consequence of the weight of the strata; and says, on the former point, "the thicker the deposit, the hotter will its lower portions tend to grow, and if thick enough they may grow red-hot, *or even melt*. In the latter case, their supports, being also melted or softened, may wholly or partially yield *under the new circumstances of pressure*, to which they were originally not adjusted; and the phenomena of earthquakes, volcanic explosions, etc., may arrive, while, on the other hand, if no cracks occur and all goes on quietly, the only consequence will be . . . . in a word, the production of Lyell's metamorphic rocks." Dr. T. Sterry Hunt, in a paper on mountains, adopts the views of Herschel as to the cause of the subsidence and the rising of heat from below, and adds that the lines of weakness being established by the softening of the bottom strata through the heat received from below, "would determine the contraction which results from the cooling of the globe to exhibit itself in those regions and along those lines where the ocean is subsiding beneath the accumulating sediments."

(5.) The stratified rocks become, in the partial collapse, upturned or folded, and pressed into a narrower space than they occupied before, much fractured and faulted; and finally — for such processes move on slowly — a mountain range exists as the result. The crust

beneath was that of the geosynclinal; and lateral pressure, however powerful, could not possibly have raised at the time the downward-flexed crust. The pressing of the *beds* into a narrower space would have given more or less of elevation to the upturned mass, as Le Conte has remarked.

One or more profound fractures and great faults are a feature of the process, as recognized by Suess in his memoir on mountain-making, and the profoundest is commonly to the rear of the axis, and not on the shoving side. The greatest in the Green Mountains and in the Appalachian range was on the western side, not on the eastern, or shoving side. In the Sierra Nevada it appears to have been on the east side, or, again, away from the ocean, this slope of the Sierra being very steep compared with the western (p. 797).

In the Juras, Apennines, Carpathians, and Alps, which have the inequilateral features of the Appalachians, one side, as Suess observes, "is the side of shoving and folding, the other of fracture, and, in the Apennines, of volcanic phenomena." The fracture line of the Juras is turned toward the Alps. "The western Alps repeat the same contrast of a folded outer side and an inner side of fracture, though here the volcanic mountains are wanting."

2. *Character of the Mountain Range thus made.* — The mountain range, begun in a geosynclinal, and ending in a catastrophe of displacement and upturning, is appropriately named a *synclinorium*, it owing its origin to the progress of a geosynclinal. [The word is from the Greek for synclinal, and ὄρος, *mountain*.]

The resulting mountain structures vary greatly; but the process is fitted to produce all variations; for the gentlest and broadest flexures, as well as the steepest and closest; for joints and slaty cleavage; for fractures of the extremest kind, giving exit or not to floods of igneous rock; for breakings and crushings of strata of indefinite amount; and also, — since heat would be a certain result of the friction, and that so derived would be added to heat from below (p. 718) — for metamorphism of every possible grade, from oxydation or deoxydation to the making of silicates and diamonds, from the reddening and baking of sandstones to the complete crystallization of strata, and even the production of granite, either in veins or terranes, or as the axial core of a mountain ridge.

Synclinorial ranges differ much as to the amount of disturbance, the character and number of the ranges of folds, the existence of a granitoid axis or not, and the occurrence among the attendant phenomena of igneous eruptions or not. The Sierra Nevada is an example of a single mountain mass, with a granite axis (p. 797). Its volcanic phenomena are probably of later origin. The several areas

of the Triassico-Jurassic sandstone (p. 403) were areas of subsidence, or sinking troughs, and sedimentary accumulations in progress in each trough; and the geosynclinal, in each case, ended in catastrophe, as exhibited in upturned or displaced rocks, and in lines of extensive igneous ejections. The progress was that of a synclinorium, although no true mountain range was made.

Whether the fusion of the liquid rocks of volcanoes and of igneous ejections is to be included among the effects of the lateral pressure which has made mountains, or not, is doubtful. It seems hardly possible that the great lines of igneous eruption and of lofty volcanic cones over the globe could have originated from fusion of material in the supercrust. A series of fractures and outflows, but a thousand miles long, like that of the Mesozoic era on the Atlantic border of North America, is long compared with the probable thickness of the earth's crust. It is not possible that the fusion of just the same kind of rock could have been produced by friction within the variously composed beds of the thin supercrust along so extended a line, especially from such feeble movements as are indicated by the slightly upturned Mesozoic beds. But the small upturnings and fracturing of these beds were a consequence of fracturings of the earth's crust beneath; and, as Prof. E. W. Hilgard has said, there may have been, in such cases, friction enough (along these deep fissures) to cause an extensive fusion of the *lower portion of the crust* where the temperature was near the melting point; and uniformity of constitution in the ejected material would be a natural consequence of such conditions. This method is but a step removed from that which derives the material from liquid rock below.

The strongest argument in favor of friction in the supercrust as a source of volcanic heat and fusion (or of the part not received from lower depths in the crust) is derived from the resemblance of many trachytes to ordinary granites, and of dolerytes to the Archæan norytes or hypersthenytes. But the material of the granites and norytes was derived originally from the fused material of the globe; and trachytes and dolerytes have flowed out from the largest craters of volcanic lines, as well as from local vents. It is hence possible that all trachyte and doleryte may have had the deeper source, while not impossible that part may be a result of fusion through friction in the supercrust. The fact that granitic material has been put into the pasty state by the heat of metamorphism is strong reason for admitting that the freer fusion needed to make trachyte may have come from like conditions.

The final shaping of the range is carried on afterward through erosion, which usually carves valleys out of anticlinals and ridges out of synclinals (p. 652); and the shallower synclinals of greatest breadth and depth, other things being equal, often become ultimately the highest of the mountain ridges, because more material is embraced in them. Some examples of this exist in Graylock and Mount Washington, and other high summits of the Taconic Range of western

Massachusetts and Vermont, a western section of the Green Mountains.

3. *Consequent Character of Mountain Chains.* — (1.) Mountain chains are combinations of mountain ranges of the synclinorial kind, with usually other results as to altitude and fracture from subsequent geanticlinal movements. It has been already explained that the Appalachian Chain and the Rocky Mountains are of polygenetic origin (p. 796); and these are examples of the general fact. The geanticlinal movements may have followed soon upon the making of the range, or have accompanied it; but, in general, they have come long afterward. The Wahsatch Mountains now have a height of 12,000 to 14,000 feet above the sea level; but if the mass of the Rocky Mountains had not been raised during the Tertiary, after they were made, 10,000 feet, their altitude would have little exceeded that of the Appalachians. And while a geanticlinal movement of 10,000 feet in elevation has taken place on the western portion of the continent since the Cretaceous period, one of 500 feet, to, perhaps, 1,000 feet, has occurred on the Atlantic border, adding this much to the elevations of the Appalachians and other mountain areas.

(2.) Successive synclinoria have rarely been made with a common axis. The region of a synclinorium ends in becoming a part of the stiff, unyielding and stable crust, apparently because of the solidification, and often, in parts, the complete crystallization, undergone during its formation. The locus of the next progressing geosynclinal is hence likely to be on one side or the other of the axis of the preceding finished synclinoria. The range of the Adirondacks lies to the *west* of the Green Mountain range, and that of the Blue Ridge of Virginia and North Carolina, also Archæan, to the *east* of the Appalachian range; and after the last mentioned synclinorial range was completed, another was in progress to the eastward of the former synclinoria, both in New England and to the southwest — that of the Triassico-Jurassic beds. This shifting of the region to one side and the other has tended to give the great width to the mountain chains.

(3.) Further, the thickening of the earth's crust with the progress of time has caused a gradual change in the character of mountain-making.

After the crust had become thickened by the earth's internal cooling through the ages, and had been stiffened also by the plication and solidification, and partly the crystallization, of the strata of the super-crust, geosynclinals became less a possibility; and, consequently, the chief movement in mountain regions, caused by the ever-continuing lateral pressure, was an upward one, and mountain chains thereby received their great heights largely in the Tertiary. For the same

reason, the areas over the earth's surface that were affected by single movements were of very vast extent. Of this kind were the high-latitude movements of the Quaternary. Besides the downward bending over those higher latitudes in the middle Quaternary, there was another in the warm parts of the oceans — the coral-island subsidence. Both bear the character of the times in the extent of surface involved, and are wholly unlike the mountain-making geosynclinals of earlier time. It is probable that the Pacific coral-island subsidence, or geosynclinal, was the counterpart of the geanticlinal over the continents of the later Tertiary and early Quaternary.

For a similar reason, fractures and outflows of igneous rocks became numerous after the crust had become too much stiffened to bend easily. Great floods of doleryte and trachyte were poured out over the Rocky Mountain slope after the close of the Cretaceous period. The previous plications and solidifications of the strata, involved in the making of the various ranges of mountains on the Pacific side of the continent — the Sierra Nevada and the coast ranges on the west, and the Wahsatch and other mountains on the east — had left the crust firm and unyielding; and, being too stiff to bend, it broke, and out leaped the fiery floods.

From the descriptions of the Henry Mountains, of Western Colorado, by Mr. G. K. Gilbert, it appears that mammiform bulgings of the strata (Cretaceous to Subcarboniferous), with quaquaversal dip, were made, even to a height of 5,000 feet above the surrounding plateau, by the injection of trachyte into chambers between beds at different levels in and over the Carboniferous, which chambers were opened, in his view, by the forcibly upthrust liquid rock. (See p. 747). He applies the term *laccolite* (from λάκκος, *cistern*, and λίθος (better *laccolith?*) to such injected masses.

4. *Valleys.* — The valleys of the world are mostly *valleys of denudation*, and, as has been stated, they are the work chiefly of the fresh waters of the land; the sea and the winds having contributed little toward the great result. The channels now occupied by the sea, called fiords, and a large part of the bays, besides many straits or channels among off-shore islands, are embraced among the results of erosion by fresh waters.

There are besides, *inter-accumulation depressions*, as the previous descriptions have shown. They are regions left relatively low, owing to accumulations either side. Circumstances sometimes favor the deposition of material along lines, or bands, where the region between remains low without any help from erosion. The forming of beaches and drift heaps may result in little valleys or relatively low areas of this kind; and if the beaches consist of coral or shell sand, the accumulation becomes a bed of limestone. Where subsidence is added, the depression is an effect of combined accumulation and subsidence, and has, in some instances (as between coral islands) become thou-

sands of feet in depth. Another kind of inter-accumulation depression is the interval between volcanic mountains or igneous outflows.

Besides these sources of valleys or depressions there are others directly connected with movements in the earth's crust or mountain-making processes.

(1.) *Geosynclinal Depressions:* Or those made by downward bendings of the earth's crust, producing broad basins, too shallow to be called valleys, such as have existed over the surface of the continents and along their borders during the progress of rock-making. Such depressions are not now distinguishable from Intermont valleys.

(2.) *Synclinal Valleys:* The synclinal depressions made in the folding of strata, alternating with anticlinals, few of which still exist as valleys, or even as depressions, owing to the degradation which such regions have undergone.

(3.) *Valleys or Depressions of Subsidence:* Made by subsidences or down-throws in connection with fractures. These depressions also have generally been obliterated by denudation, excepting those of recent origin.

(4.) *Fissure Valleys:* The fissures that were left wide open after a time of fracturing, instead of becoming filled with mineral material. Many such have existed; but denudation has, in general, obliterated them. Running waters have made nearly all the profound fissure-like channels of the world, and have not needed a fissure to initiate the work, though sometimes thus aided.

(5.) *Intermont Valleys:* Depressions made by upliftings on either side of a region; or the intervals between mountain chains or mountain ranges: as that of the broad Mississippi valley, between the Appalachian and Rocky Mountain chains; that of Lake Champlain, between the Green Mountain range and the Adirondacks; that of the Connecticut valley; and others, between the Blue Ridge and ridges of the Appalachians.

(6.) *Contractional Depressions:* Made by contraction from cooling. The oceanic depression is such a depression, or rather a combination of depressions so made.

The depressions of the Great Lakes of North America are among the earth's larger valleys. The surface of Ontario is 233½ feet above the sea; but its bottom is 600 feet below its outlet, and over 360 feet below the sea; and Lake Superior, which at surface is 627 feet above the sea, has a mean depth of about 1,000 feet. Such depressions cannot be wholly valleys of erosion, or simple synclinal valleys. They may be geosynclinal in origin; but seem rather to be depressions of the Intermont kind, and to exist because (p. 394) the region lay near the borders of the stable Archæan mass, against which the continent to the south and east was pressed in the oscillations of later time.

4. EVOLUTION OF THE EARTH'S FUNDAMENTAL FEATURES.

The making of mountains involves the making of the earth's fundamental features. The following are some general considerations bearing on the geographical positions of mountains and their relations to the continental plateaus and oceanic depressions : —

1. *Action of the Pressure against the Continental borders.* — The positions of the great mountain-chains along the borders of the continents, and of uplifts, fractures, plications, volcanoes, metamorphism, chiefly on the seaward slope of the chains, prove that, while the force from contraction was a universal force over the sphere, the lateral pressure was vastly more effective in a direction from the ocean than in the reverse direction. Now this landward action of the force seems to be a necessary consequence of the fact that the crust over the oceanic areas was and is abruptly depressed below the level of the continental, so that the lateral pressure from its direction would have had the advantage of leverage beneath the Continental crust, or, rather, would have acted obliquely upward against it.

In the case of the Appalachians and the other ranges of the Atlantic border, the mountains *front* toward the ocean; that is, have their steepest folds on the oceanic side; and this is a common fact. But the Juras, on the contrary, front inland, toward the Alps, and apparently because of their subordinate relations to the Alps, both geographically and genetically. In each case they were on the shoving side; while the greater fractures are usually toward the opposite side.

2. *Pressure against the Continental Borders greatest on the sides of the largest Oceans.* — The fact that the largest and loftiest mountain chains, greatest volcanoes, and other results of uplifting and disruptive force, characterize the borders of the *largest* oceans, shows that the shoving action from the direction of the oceans was approximately proportional to the extent of the oceanic basins.

3. *Universality of the Great Movements.* — The universality of the great movements resulting from the earth's cooling and contraction is manifested, not only in the relations existing between the continental features and the positions of the oceanic basins, but also in the fact that *contemporaneous*, *parallel* movements have taken place in the continents on the opposite sides of the same ocean, and probably in some cases in all continents together. This point is illustrated on page 784. We repeat but one of the facts. The great era of mountain-making, which commenced in the early Tertiary and continued to its end, was a mountain-making era for all continents alike; in Asia and South America, as well as Europe and North America, mountain ranges were raised over 10,000 feet.

Again, the mountain ranges made at different times on the same side of a continent have been alike in general direction (p. 796); in-

dicating that the all-pervading force was in each place at its old work, through all the successive ages, with but small modifications from the changed conditions.

The force has thus acted as if one in origin and nature, and has manifested at all times the fact that one single system of evolution was in progress.

The shrinkage in the earth *as a whole* made its mountain ranges, although these are so localized geographically and chronologically. All the shrinkage that took place during the Paleozoic ages succeeded in producing (as at present understood) in the North American continent only one mountain line; the Green Mountain part of it after the Lower Silurian era, a small northeastern portion in the Devonian, the Appalachian portion after the Carboniferous. It is not at present easy to calculate the amount of shortening of the circumference of the globe, indicated by the facts; but, considering the length of Paleozoic time, it appears safe to believe that there was fully enough in the sphere between the middle of the Atlantic on the east and the middle of the Pacific on the west, for the result. Europe has little to show for the same era excepting the Urals, on its eastern border. What was done in Asia is yet undetermined.

4. *The System of Trends.* — While the relative positions of the continental plateaus and oceanic basins have influenced the general direction of the action of lateral pressure, some unexplained cause — perhaps the existence of a cleavage structure in the crust, or at least the existence of directions of weakest cohesion, in part controlled the courses of fractures and uplifts, somewhat as the warp and woof in a piece of cloth fix the courses of rents, while the direction of the force applied determined the positions and extent of the rents. Force exerted at right angles to the lines of structure, and equal along the course, would produce a straight series of rents or uplifts (Figs. 11, 12, p. 19). If not equal along a given line, the series of rents made, taken together, might be oblique or else curving in its axial line (Figs. 13, 14, 15). If the pressure were oblique to the structure-courses, the series of rents would be an oblique series, and, as above, either straight or curved. Hence, curves would be necessarily in the system.

The North Atlantic follows one of the great courses, and the Pacific another (page 35). North America is bounded by the two, and hence its triangular form. The coincidence between the trend of the Pacific (northwest and southeast), the mean trend of the Pacific islands (p. 33), and the axis of the coral-island subsidence (p. 583), shows that the ocean in its movements has been one great area of oscillation. The central curving range of that ocean, five thousand five hundred miles long, lies on the southern side of the axis of this

great approximately-elliptical area. Recent deep-sea soundings confirm the conclusion, drawn by the author from the sizes of the atolls over the Pacific, that the axial area north of the equator, where no islands occur, is the region of greatest depth.

The double or triple system of curves around Australia, from New Hebrides, or perhaps northern New Zealand, to New Guinea and Timor, are such as might arise from pressure acting against that stable continental area of Australia, for they are concentric with it; and the branch of the central Pacific chain, leading off westward through the Carolines, has been shown, on page 34, to conform to this Australian system. The rising curve from Java, through Sumatra, suggests that here pressure acted from the direction of the Indian Ocean as well as the Pacific; and this is further confirmed by the fact that the deep-water channel, separating the Australian seas from the Asiatic, passes just north of New Guinea and Celebes, and south of Java.

The East Indian Archipelago lies between the North Pacific and the Indian Ocean; and the two, along with the reacting stable continental areas, have together modeled out the group. The West Indian Archipelago has a similar position between the North Atlantic and the South Pacific, and hence the resemblances to the East Indian, pointed out on pages 35, 36.

The curves along eastern Asia, in the islands and continental mountain-ranges (page 35), seem to show that the pressure from the direction of the Pacific, which produced the curves, was unequal along different parallel lines. The courses and positions of the groups of Pacific islands prove that the bottom has its ranges of southeast and northwest elevations and depressions, crossing the ocean; and this would occasion the unequal action required.

5. *America simple in Evolution, because of its situation between the Great Oceans.* — From the above, we perceive why it is that North America should illustrate most simply and perfectly the laws of the earth's genesis. Unlike the other continents, it is bounded on all sides by oceanic basins; on one side, the North Atlantic with a northeast trend; on the other, the greater Pacific with a northwest trend. The conditions under which the lateral pressure acted were, therefore, the simplest possible; and the evolution was, consequently, regular as well as systematic. Europe has Africa on the south, and Asia on the east, and hence the complexity in its feature lines; yet, even amid that complexity, results according with the general principles here explained may be made out.

5. *Arrangement of the Continents and Oceans.* — Why the continents are gathered about the North Pole, and the waters about the

South, science does not explain. North America began its development at the north, and in its growth spread southward. The same was true of Europe, although the fact is less pronounced. It may have been so of South America, although her northern extremity is beneath the equator. But of Asia too little is known to warrant the assertion that she has conformed to this principle; and still less is known of that highest of continents, so far as average level is concerned — Africa. Further, astronomy does not allow geology to conclude that the prevalence of water about the South Pole is sure evidence of less or lower land than at the north, — teaching that if the earth's mass has greater density there it would have more water through its attraction.

6. *Climatal Development.* — A globe that has slowly cooled from fusion, has had continents and mountain chains in progress of development, and has had in the past, as now, a sun that is losing heat like itself, must have been, and be, a globe also of cooling climates. But its orbit has wide variations; its continents have passed not only from the stage of submergence to that of emergence, but have made the transition back and forth, more or less completely, many times; and the sun and stars have their varying phases; moreover, the present era is a time of mild climate compared with that of the Glacial period which preceded it, and hence the cooling of the climates has not been a continuous and regular change, but one by oscillations, in which refrigeration was real, though often passing through extremes in both directions. Agassiz first suggested that the times of great exterminations of life over the globe were epochs of unusual cold, if not of a true glacial era. The first such epoch that is distinctly indicated occurred near the close of the Paleozoic era, and it was a time of the most general extermination in geological records. In Britain the Permian bears evidence of floating ice in its stony accumulations (p. 431); in India the Permian contains bowlders of all sizes, up to five or six feet, and also glacial scratches; and similar facts have been observed in rocks supposed to be of the same age in the southern part of Africa. The character of the Triassico-Jurassic rocks of Eastern America bear evidence of ice-action in some part of the era of their origin. The exterminations of life at the close of the Cretaceous is attributed to the same cause on page 488; but the proof from the condition of the rocks themselves is less decisive. Sufficient, however, is known to establish the fact of oscillation in the development of the earth's climates, and to sustain the view of Agassiz that the cold extremes have been times of unusual catastrophe to the life of the globe.

Further: changing climates have occasioned changing rates of erosion and sedimentary deposition; have made, over large continental

areas, times of great precipitation to alternate with times of prevailing drought; times of full lakes and of large hard-working rivers, with times of dwindled or feeble waters; times favoring the wide distribution of forests and abundant vegetation with times of lessening forests and widening barrens, and of exterminations among both vegetable and animal species. All attempts therefore to find, in the results of aqueous action, a definite measure of any part of the geological past are necessarily futile; as another has recently said, "it is the duty of geologists to point out the impossibility of correlating historical and geological time."

7. *Accordance with the Universal Law of Progress.* — The general law at the basis of all development is strikingly exhibited in the earth's physical progress. The law is simply this: Unity evolving multiplicity of parts, through successive individualizations, proceeding from the more fundamental onward.

The earth in igneous fusion had no more distinction of parts than a germ. Afterward, the continents, while still beneath the waters, began to take shape. Then, as the seas deepened, the first dry land appeared, low, barren, and lifeless. Under slow intestine movements, and the concurrent action of the enveloping waters, the dry land expanded, strata formed; and, as these processes went on, mountains by degrees rose, each in its appointed place. Finally, in the last stage of the development, the Alps, Pyrenees, and other heights received their majestic dimensions; and the continents were finished to their very borders.

Again, as to the history of fresh waters. The first waters were all salt, and the oceans one, the waters sweeping around the sphere in an almost unbroken tide. Fresh waters left their mark only in a raindrop impression. Then the rising lands commenced to mark out the great seas; and the incipient continents were at times spread with fresh-water marshes, into which rills were flowing from the slopes around. As the mountains enlarged, the rills changed to rivers, till at last the rivers also were of majestic extent; and the continents were throughout covered with streams at work, channeling mountains, spreading out plains, opening lines of communication, and distributing fertility everywhere.

The organic history of the earth, from its primal simplicity to the final diversity, has been shown to exemplify in many ways the same great principle.

Thus the earth's features and functions were successively individualized, — first, the more fundamental qualities, and finally, those myriad details in which its special characteristics, its magnificent perfection, and its great purpose of existence and fitness for duty, largely consist.

Conclusion. — The causes of the earth's movements, which have been considered, appear to explain the evolution of the prominent features of the globe; and the special history made out for North America may be safely regarded as an example of what will hereafter be accomplished for all the continents.

But Geology, while reaching so deeply into the origin of things, leaves wholly unexplained the creation of matter, life, and spirit, and that spiritual element which pervades the whole history like a prophecy, becoming more and more clearly pronounced with the progressing ages, and having its consummation and fulfillment in Man. It gives no cause for the arrangement of the continents together in one hemisphere (p. 10), and mainly in the same temperate zone, or their situation about the narrow Atlantic, with the barrier-mountains in the remote west of America and in the remote east of Europe and Asia, thus gathering the civilized world into one vast arena (p. 29); it does not account for the oceans having, in extent and depth, that exact relation to the land which, under all the changes, allowed of submergence and emergence through small oscillations of the crust, and hence permitted the spreading out of sandstones and shales by the waves and currents, the building up of limestones through animal life, and the accumulation of coal-beds through the growth of plants, — and all in numberless alternations; nor for the various adaptations of the system of plants and animals to the wants of the last species in that system. Through the whole history of the globe, there was a shaping, provisioning, and exalting of the earth, with reference to a being of mind, to be sustained, educated, exalted. This is the spiritual element in geological history, for which attraction, water, and fire have no explanation.

The following are the titles of important works and memoirs on mountain-making, on the origin of the earth's structure, and on cleavage and foliation. One is added that was omitted under the subject of Volcanoes.

Since the Taconic system has been recognized by some geologists as including an independent range of elevations and disturbed rocks, extending uninterruptedly from Maine to Georgia, and even from the Taconic mountains around the world, the titles of the more prominent papers on this system, *pro* and *con*, are added.

1. British and European.

Gregory Watt: Observations on Basalt, etc., Phil. Trans., 1804, p. 279; gives a detailed account of the melting of 700 pounds of basalt from Rowley-Rag (G = 2·743), to glass, and of its becoming, on slow cooling, a gray, crystalline-granular mass (with G. = 2·934–2·949) consisting of spherical concretions, many two inches in diameter, and having a somewhat radiated structure (which was mostly lost with the slowest cooling); and of the adjoining concretions being often rendered hexagonally prismatic from contact, whence he infers the concretionary origin of basaltic columns.

James Hutton: Theory of the Earth, R. Soc. Edinb., 1778; 8vo, 1795; attributes mountains to subaerial denudation after an elevation of a region by the earth's central heat.

DESCARTES: Principia Philosophiæ, 1644. Advocates the former fluidity of the earth, and makes dislocations over the surface an effect of contraction beneath.

JAMES HALL: On the Convolutions of strata at their junction with Granite, Trans. Roy. Soc. Edinburgh, vii., 79, 1815 (read in 1812); attributes folding to lateral pressure, and speaks of his having reached this conclusion first in 1788.

CORDIER: Temperature of the Interior of the Earth. Mem. Acad. Sci., Paris, vii., 473, 1827; advocates the doctrine of the earth's interior liquidity.

S. D. POISSON: Théorie Mathématique de la Chaleur, 1835. On the Temperature of the Solid Parts of the Globe, etc., Comptes Rendus, 1837; Amer. J. Sci., xxxiv., 57, 1838; sustains the doctrine of the earth's interior solidity.

H. T. DE LA BECHE: Geol. Researches in Theoretical Geology, 1834; advocates folding by lateral pressure, and the making of mountains by the earth's contraction, and announces the distinction of basic and acidic rocks.

G. POULETT SCROPE: On Volcanoes, see page 748.

C. BABBAGE: On the Temple of Serapis (see page 722); besides recognizing the relations of isogeothermal planes, and the effect upon them of surface changes whether removals of rock material or accumulation, the memoir accounts for changes of level through the expansion or contraction caused by changes in the subterranean heat or in the position of these isogeothermal planes.

L. ÉLIE DE BEAUMONT: Les Systèmes des Montagnes, Ann. des Sci. Nat., Sept., Nov., Dec., 1829; Révue Française, May, 1830; Bull. Soc. Géol. de France, II., iv., 864, 1847, and in 3 vols., 1543 pages, 12mo, Paris, 1852; advocates the view that mountain ranges of the same age have the same trend, whence the trend is indicative of the time of origin, and also the sudden upheaval or *soulèvement* of mountain chains.

CHARLES LYELL: Principles of Geology, 1st edit., 1830 and 1832; last in 1867.

CHARLES DARWIN: Geological Observations on South America (made on the voyage of the Beagle), 8vo, 1846; among its subjects, treats of foliation on page 168.

WM. HOPKINS: Researches in Physical Geology, Proc. Brit. Assoc., 1837; Trans. Cambridge Phil. Soc., vi., vii., 1835; treats of the phenomena of elevation, fractures, and joints. — Phil. Trans. 1839, p. 381; 1840, p 193; 1842, p. 43; treats of the bearing of the amount of precession and nutation on the question of the earth's interior fluidity and the thickness of the crust; also of the solidification of the earth, of a superficial crust forming over a liquid mass, with probably a solid centre, and of the final obliteration of the viscous layer between the crust and the solid centre, leaving in its place only cavities of liquid material to sustain volcanic action. — On Elevation and Earthquakes, Rep. Brit. Assoc., 1847. — Changes in the Earth's Climate, Quart. J. Geol. Soc., viii., 56, 1852; Amer. J. Sci., II., xv., 72, 1853. — De Beaumont's Theory of Mountains, Quart. J. Geol. Soc., ix., 1853.

CONSTANT PRÉVOST: Sur les Théorie des Soulèvements, Bull. Soc. Géol. de France, xi., 183, 1840; opposes the *soulèvement* theory of De Beaumont, and advocates the contraction theory.

DUROCHER: On Comparative Petrology; Comptes Rendus, 1857, xliv., 325, 459, 605, 776, 859; Ann. Mines., V., xi., 217, 1857; presents his view as to basic and acidic magmas in two parallel layers beneath the crust, with the acid one above, as the source of the basic and acidic eruptive rocks. An English translation of Durocher's Memoir is contained in the Manual of Geology of Rev. S. Haughton, 2d ed., 16mo, London, 1866.

J. F. W. HERSCHEL: On the Secular Variations of the Isothermal Surfaces of the Earth's Crust, Proc. Geol. Soc., ii., 548, 596, 1837. — Phys. Geogr., 1859, p. 116 (Art. in Encycl. Britannica, xvii., 1859); and Appendix to Babbage's Ninth Bridgewater Treatise; attributes changes of level to "changes in the incidence of pressure on the general substratum of liquified matter which supports the whole;" argues that the rise of Scandinavia may be caused by the accumulation of sediments deposited over the adjacent ocean's bed. See also p. 820.

J. H. PRATT (Archdeacon): The Figure of the Earth, 12mo, 1st edit. in 1860, 4th in 1872; in the earlier additions attributes the origin of oceanic depressions and continents, and also of mountain chains, to unequal contraction in a cooling globe, but in

the last, refers the formation of mountains to lateral pressure; concludes that "the crust beneath the oceans is of greater density than the average portions of the surface," that is, that where the contraction was greatest the density of the rock-material below is greatest, and proportionally so. — On the Constitution of the Solid Crust of the Earth, Phil. Trans., 1871; Nature, iv., 28, 141, 344, 1871.

DELAUNAY: Review of Hopkins, etc., Comptes Rendus, 1868, Geol. Mag., v., 507. Bearing of the results of astronomy on the thickness of the earth's crust, Comptes Rendus, March, 1871.

H. HENNESSY: Researches on Terrestrial Physics (with review of Hopkins on the Condition of the Earth's Interior), Phil. Trans., 1851. — Influence of the Earth's Internal Structure on the Length of the Day, Phil. Mag., 1856. — Rigidity of the Earth (in review of W. Thomson), Nature, v., 288, 1872. — Internal Fluidity (favoring fluidity), Comptes Rendus, March, 1871, and Geol. Mag., viii., 216, 1871. — Limits of Hypotheses regarding the Properties of the Matter composing the Interior of the Earth, Phil. Mag., Oct., 1878, Rep. Brit. Assoc. for 1878, Amer. J. Sci., III., xvi., 461.

WILLIAM THOMSON: Dates from Terrestrial Temperatures, Rep. Brit. Assoc., 1855. — Secular Cooling of the Earth, Trans. R. Soc. Edinburgh, xxiii., 157, 1862. Decrease in the Length of the Day owing to Tidal Friction, ibid. and Thomson and Tait's Natural Philosophy. — On the Rigidity of the Earth, Proc. Roy. Soc., xii., 103, 1862; Nature, v., 223, 1872. — On Geological Time, Trans. Geol. Soc. Glasgow, iii., pt. 1, and on Geological Dynamics, ibid., pt. 2; Geol. Mag., vi., 472, 1869; Nature, i., 507. — Internal Fluidity of the Earth, Nature, 5, 257, 1872. — Address at the Glasgow Meeting of the Brit. Association, in 1876, Rep. Brit. Assoc. and Amer. J. Sci., III., xii., 336; withdraws his former argument from precession and nutation as to the earth's rigidity.

T. H. HUXLEY: Address to the Geological Society of London, Quart. J. Geol. Soc., xxv., 1869; alludes to Thomson on Geological Time.

O. FISHER (Reverend): On the Elevation of Mountain Chains, with a Speculation on the Cause of Volcanic Action, Cambridge Phil. Soc., 1868, and abstract in Geol. Mag., v., 493, 1868; makes lateral pressure the fundamental agency; and also urges that mountain-raising makes cavities beneath, and causes thereby diminution of pressure, and thence may come fusion and igneous phenomena. — On the Formation of Mountains, with a Critique on Capt. Hutton's Lecture, Geol. Mag., x., 248, 1873.

DAVID FORBES: Nature of the Earth's Interior, Geol. Mag., viii., 162, 1871; makes 50 m. in thickness of crust, a liquid layer 400 m. thick, and the rest solid.

HUTTON (Captain): On the Formation of Mountains, Geol. Mag., x., 166, 1873.

E. SUESS: Entstehung der Alpen, 8vo, Vienna, 1875; abstract in Amer. J. Sci., III., x., 446, 1875; see pp 807, 821.

A. DAUBRÉE: Études Synthétiques, etc., see page 770; in this important volume, the facts from observation and experiment relate not only to the origin of minerals, veins, ore-deposits, and metamorphism, but also to the flexing and fracturing of strata, the origin of faults, joints, and slaty cleavage or lamination, the distorting of fossils, and the effects of contraction as illustrating mountain-making.

A. HEIM: Mechanismus der Gebirgsbildung, im Anschluss an die geologische Monographie der Tœdi-Windgællen-Gruppe, 2 vols., 4to, Basel, 1878; describes, with great fullness, the rocks and structure of a part of the Alps, and ably discusses the subject of mountain-making; holds that the foldings in the rocks have come from the earth's contraction on cooling, and that a contraction of 1-100th of the earth's circumference would have probably sufficed to make all the flexures of mountains found on the meridian crossing the Alps; and that the actual lessening of the earth's radius by the contraction is about 50,000 meters.

S. HAUGHTON (Reverend): Notes on Physical Geography, Proc. Roy. Soc., 1877, 1878; in the earlier of these papers treats of the shifting of the earth's axis; in that of April 4, 1878, gives for the time-ratios for the Archæan, Paleozoic, and subsequent time, as deduced from the maximum thickness of the strata, 34·3 : 42·5 : 23·2, and, as deduced from his calculations as to the secular cooling, 33·0 : 41·0 : 26·0; and concludes, from the present rates of denudation and the maximum thickness of the earth's strata (very uncertain data?) that the minimum duration of geological time is 200,000,000 years.

G. H. Darwin: Influence of Geological Changes on the Earth's Axis of Rotation, Proc. Roy. Soc., Nov., 1876. On the Formation of Mountains and the secular cooling of the earth, Nature, Feb. 6, 1879; Amer. J. Sci., III., xvii., 320, 1879.

A. Sedgwick: On the Structure of Large Mineral Masses (Cleavage, etc.), Trans. Geol. Soc. of London, II., iii., 479, read March, 1835; the distinction of slaty cleavage from bedding here first brought out. — On the Classification of the fossiliferous slates of North Wales, etc., Quart. J. Geol. Soc., iii., 133, 1847; treats anew of the subject of cleavage, and discusses further the general coincidence between the strike of a slate and the strike of its slaty cleavage.

W. Sharpe: On Slaty Cleavage, Quart. J. Geol. Soc., ii., 309, 1846; iii., 74, 1847; includes also the subject of the distortion of fossils.

H. C. Sorby: On Slaty Cleavage, Edinburgh, New Phil. Jour., lv., 137, 1853; Phil. Mag., IV., xii., 127, 1856. Microscopical Structure of Crystals and Rocks, see p. 769; advocates the aqueo-igneous origin of granite, etc.

John Tyndall: On the Cleavage of Slate Rocks, Phil. Mag., IV., xii., 44, 129; Lecture before the Royal Institution, 1856.

2. American.

W. W. Mather: New York Geological Report, 4to, 1843; advocates the contraction theory of flexures and mountain-making. Also on the Physical Geology of the United States, Amer. J. Sci., xlix., 1, 284, 1845.

W. B. & H. D. Rogers: Structure of the Appalachians, Trans. Amer. Geol. & Nat., 1840–42, 474; Am. J. Sci., xliii., 177; xliv., 359; gives full details as to facts from the Appalachians, deduces the general system in their arrangement, sets forth the relation of the whole to mountain-making, and attributes the effects to wave-like movements in the earth's liquid interior.

H. D. Rogers: Report on the Geology of Pennsylvania, 2 vols., 4to, 1858.

J. D. Dana: Origin of the General Features of the Pacific and the Globe, Rep. Wilkes U. S. Expl. Exped., 4to, 1849. — On Changes of Level in the Pacific, ibid., and Amer. J. Sci., II., xv., 157, 1853. — Origin of Continental and Oceanic Areas (by difference in rate of cooling), ibid., ii., 352, 1846; iii., 94, 1847. — Origin of Mountains by the Earth's Contraction, ibid., II., iii., 94, 176; iv., 88, 1847; III., v. and vi., 1873. — Origin of the Grand Outline Features of the Earth, ibid., II., iii., 1846; 381, xxii., 335, 1861; bringing out the relation between the extent of the great oceans on the one hand and their border features (that is the heights of the adjoining continental mountain borders, the amount of volcanic action along them, etc.), on the other, and the evolution of the North American continent.

James Hall: Theory of Mountains, Introduction to vol. iii. of N. Y. Palæontology, pp. 1–96, 1859; besides adopting Herschel's view as to the sinking of an area of accumulating sediments in consequence of the weight, and resulting displacements, announces, as a general principle, that the making of a mountain range is preceded by a thick accumulation of sedimentary beds over the area; attributes metamorphism to "motion, or fermentation and pressure," within the material of the rock itself.

G. L. Vose: Orographic Geology, Boston, 1866; argues against the theory of contraction; attributes metamorphic changes to "the enormous pressure generated in the folding of masses of rock," the pressure being that of gravitating sedimentary beds of great thickness.

J. P. Lesley: Coal and its Topography, 12mo, Philadelphia, 1856. — Second Geological Survey of Pennsylvania (under Prof. Lesley as State Geologist); publications commenced in 1875, and still in progress.

J. M. Safford: Report on the Geology of Tennessee, 8vo, 1st ed. 1856; 2d, 1869; treats of the Appalachian region in Eastern Tennessee.

T. S. Hunt: Seat of Volcanic Action, Geol. Mag. 1869, and Am. J. Sci., II., l., 21, 1870, and Geol. Mag., Feb., 1868; places this seat in a "plastic zone" made by the "aqueo-igneous fusion" of part of the lower section of the sedimentary strata. — Points in Dynamical Geology, Am. J. Sci., III., v., 1873. See, also, p. 770.

J. D. WHITNEY: Earthquakes, Volcanoes, and Mountain Building, North American Review, 1871, and also as a separate volume, 1871.

N. S. SHALER: On the Formation of Mountain Chains, Proc. Soc. Nat. Hist., Boston, June, 1866, and Geol. Mag., v. 511.

JOSEPH LE CONTE: Formation of the Great Features of the Earth's Surface, Amer. J. Sci., III., iv., 460, 1872, v., 156, 448 (the last in reply to T. S. Hunt) 1873. — Structure and Origin of Mountains, ibid., xvi., 95, 1878; Elements of Geology, 8vo, 1878; advocates the making of mountains by lateral pressure as a result of the earth's contraction, and the existence of a semi-fused (aqueo-igneously) layer between the earth's crust and a solid nucleus.

DUTTON: Critical Observations on Theories of the Earth's Physical Evolution, Amer. J. Sci., II., viii., 113, 1874; Penn. Monthly, 1876.

F. V. HAYDEN: Reports of the Geological Survey of the Territories, 1867–1876.

J. W. POWELL: Exploration of the Colorado River and its Tributaries, Washington, 1875. — Geology of the Eastern Portion of the Uinta Mountains and a region of Country adjacent thereto, with a Folio Atlas, 4to, Washington, 1876. — Geological Structure of Country North of Grand Cañon of Colorado, Amer. J. Sci., III., v. 456, 1873; describes the great monoclinal uplifts and faults. — Types of Orographic Structure, ibid., xii., 414, 1876.

G. K. GILBERT: Report on the Geology of portions of Nevada, Utah, California, and Arizona, in 1871, 1872, 1873, Wheeler Expedition, 4to, iii., Geology, 1875; contains, besides an account of the geology of the region, and a discussion of the subjects of mountain structure and erosion, a long list of the hot springs of the United States. — The Colorado Plateau, Amer. J. Sci., III., xii., 16, 85, 1876. — Report on the Henry Mountains, 4to, 1877; Amer. J. Sci., xix., 1880.

CLARENCE KING: Systematic Geology (1879), being vol. i. of the Reports (4to) on the Survey of the 40th Parallel; attributes the fusion of subterranean regions, and consequent volcanic action over a part of western North America, to the diminution of pressure resulting from the removal of surface rocks by erosion.

3. LIST OF PAPERS ON THE TACONIC SYSTEM.

I. *In favor of its inferior position and uncomformability to the New York Silurian.*

EBENEZER EMMONS: Rep. Geol. New York, 4to, 1842, pp. 113–164; announces the Taconic system as Lower Cambrian, and includes in it, besides the schists of the Taconic Mountains (in the vicinity of which, at Williamstown, Professor Emmons for a while lived), also the associated crystalline and semicrystalline limestones and quartzyte. — IDEM: Rep. Agric. New York, Part v., 4to, 1846, pp. 45–112; describes the system with more detail, and extends it to include rocks in Maine, Rhode Island, and Michigan. — IDEM: American Geologist, 8vo, vol. i., 1855, Part ii., pp. 1–124; extends the system from Maine to Georgia, divides it into Upper and Lower, the slates, limestones, and magnesian slates of the original Taconic (with their supposed equivalents) being made the Lower, and some added fossiliferous rocks [Primordial and later] the Upper. — IDEM: Report on the North Carolina Geol. Survey, 8vo, 1856, pp. 49–72.

F. MARCOU, Comptes Rendus, Nov. 4, 1861, and Proc. Boston Soc. Nat. Hist., 1862; adds the Potsdam sandstone and the gneiss of the Green Mountains to the Taconic system.

T. S. HUNT: Proc. Boston Soc. Nat. Hist., xix., 275, 1878; refers the "Upper Taconic," "wholly uncrystalline," to the Quebec Group, but the "Lower Taconic," here called *Taconian* (and made to include the crystalline schist of the Taconic Mountains, "along the outcrop" of which occur "the great masses of brown hematite ore" [or limonite], associated with magnesian limestones, from Vermont to Alabama), to the lowest Cambrian, or a still lower formation, containing *Scolithus* and *Eozoon*. — IDEM: Pennsylvania Geol. Report, on Azoic Rocks, Part i., 1878; uses the name *Taconian*, with the same definition, "but makes the Upper Taconic to include organic remains of the European Cambrian, at least as low as the Menevian."

II. *In favor of the identity of the Taconic system with part or all of the New York Lower Silurian.* (The Lower Silurian is called the *Champlain Division* by Mather.)

H. D. & W. B. Rogers: Proc. Amer. Phil. Soc., Jan. 1, 1841; make the slates of the Taconic Mountains and the rocks east and west to be Lower Silurian, and refer the slates to the Hudson River group. — W. W. Mather: Report Geol. N. York, 4to, 1843; gives many sections and announces the same conclusions, arguing against the Taconic system. — H. D. Rogers: Address, etc., Rep. Amer. Assoc. Geol. & Nat., for 1844, p. 67, and Amer. J. Sci., xlvii., 137, 1844; urges the same views essentially. — James Hall: ibid., p. 68.

T. S. Hunt, "of the Geological Commission of Canada": On the Taconic System, Report Amer. Assoc., for 1850 (New Haven meeting), says, "The results of the [Canada] survey have shown, as I had the honor to state at the last annual meeting at Cambridge [in 1849], that the Green Mountain rocks are nothing else than the rocks of the Hudson River group with the Shawangunk conglomerates, in a metamorphic condition." — James Hall: N. Y. Palæontology, vol. iii., p. 15, 1859. — T. S. Hunt: Amer. J. Sci., II., xxxi., 402, 1861 (after Logan's defining of the Quebec group); says, "the Quebec group with its underlying shales is no other than the Taconic system of Emmons." — Idem: ibid., xxxii., 427, 1861; makes the Taconic, exclusive of the slates, equivalent of the Calciferous, adding that "it remains to be seen whether Dr. Emmons can retain from the wreck of his system, the lower slates as a Taconic formation older than the Potsdam." — W. E. Logan: Geology of Canada, 8vo, 1863, p. 934; makes the system to consist, "for the greater part at least, of the strata of the Potsdam and Quebec Group." — J. D. Dana: Manual of Geology, 1863; cites and adopts the views just mentioned. — E. & C. H. Hitchcock: Report on the Geology of Vermont, 2 vols., 8vo, 1861, and Amer. J. Sci., III., xix., 236, 1880. — James Hall and W. E. Logan: Amer. J. Sci., II., xxxix., 96, 1865; refer the Hudson River slates south of Albany to the Quebec group. — T. S. Hunt: Address, etc., Rep. Amer. Assoc., for 1871; refers the Stockbridge or Green Mountain limestone to the Quebec group, and states that the conclusion of Rogers and Mather referring the Taconic system to the "Champlain Division" of the New York rocks had been sustained by subsequent observations (pp. 15 and 23).

J. D. Dana: On the Rocks of the vicinity of Great Barrington, Mass., Amer. J. Sci., III., iv., v., vi., 1872, 1873; gives sections showing the *conformability* of the Taconic slates, "magnesia schists" (slates and schists making the Taconic Mountains), Stockbridge limestone, and quartzyte (the original Taconic rocks of Emmons), and makes the limestone (on the basis of Billings's report of Wing's discoveries), Trenton and Chazy, and the Taconic schists and slates of Hudson River age. — A. Wing: Discoveries in Vermont, ibid., xiii., 1877; shows, *by their fossils*, that the "Stockbridge limestone" and "Sparry limestone" of the Taconic System of Emmons in Vermont, are Lower Silurian, from Potsdam to Trenton, inclusive, and that the Taconic slates *overlie* the limestones. — J. D. Dana: On the Relations of the Geology of Vermont to that of Berkshire, ibid., xiv., 1877; gives new sections proving the conformability before announced, and sustains the conclusion that the Taconic schists and slates (those of the Taconic Mountains) are of Hudson River age, and the limestones Lower Silurian. — Frederick Prime, Jr.: Lower Silurian Fossils in Limestone associated with Hydromica Slates in Eastern Pennsylvania, ibid., xv., 261, 1878; shows the Chazy, or Trenton age of the rocks, which are part of the so-called Taconic and like those of Berkshire. — T. Nelson Dale: Discovery of fossils, *proving the Hudson River age* of the supposed Taconic Poughkeepsie slates. — J. D. Dana: On the Hudson River Age of the Taconic schists, ibid., xvii., 375, 1879; announces the discovery of Trenton fossils in the Barnegat or Wappinger Valley limestone (which adjoins the Poughkeepsie slates), and proves the conformability of the Poughkeepsie slates with the slates of the Taconic Mountains, as exhibited in Mather's sections and the continuity of the Dutchess County slates and limestones with those of the Taconic System of Massachusetts and Vermont. — W. B. Dwight: Fossils of the Wappinger Valley Limestone, ibid., 389; adds to the number of localities, and gives lists of Trenton fossils. — Whitfield: On the occurrence of Maclurea of the Chazy beds in the Barnegat Limestone near Newburgh, New York, Amer. J. Sci., xvii., 1879.

VIII. EFFECTS REFERRED TO THEIR CAUSES. RECAPITULATION.

In many cases, the same effect — the formation of valleys, for example — has come from different causes; and the subject is therefore discussed in different places, in the course of the preceding pages on Dynamical Geology. In this chapter, the pages are mentioned where each topic is considered; and under some subjects additional explanations are introduced.

I. Fragmental Material or Deposits.

1. Sources of Sand, Gravel, Stones.

A. *Mechanical.* — 1. From erosion by water, pp. 648, 680.

2. From erosion by means of winds, p. 632.

3. From the abrasion of rocks or stones moved by ice, pp. 538, 699.

4. From the abrasion of opposite walls of fractures.

5. Through the freezing in the crevices of rocks, a very efficient agency in regions of cold winters, p. 687.

6. Through the divellent action of the growth of vegetation in crevices or fissures — a work in which all kinds of plants serve, from Lichens and microscopic fresh-water Algæ to great trees, and which produces vast results, p. 607.

7. Through the mutual attrition of rocks or stones in a slide, p. 665.

8. Through ordinary changes of temperature, expanding and contracting the superficial portion of a rock, p. 720.

9. Through the explosion of bubbles of lava in a volcano, producing volcanic cinders, and the material of tufas, p. 728.

10. Through the tearing action of the ice of the under part of a glacier, p. 538.

B. *Chemical.* (1) Through the chemical alteration or decomposition of one of the essential or adventitious constituents of rocks, p. 703.

(2.) Through the action of acid or alkaline solutions from some external source, p. 705.

2. Rounding of Stones, Making Bowlders. — (1.) Through the attrition caused by moving waters, air, or ice.

2. Through the loosening of surface-grains or outer layers in succession, by ordinary alternations of surface temperature, the action from two directions at the edges, and from three at the angles, ultimately producing curved surfaces, p. 720.

3. By decomposition at the surface — a cause, that, like the last, removes the edges and angles most rapidly, p. 87.

4. By revolution in the air, on ejection to a considerable height from the throat of a volcano, producing what are called volcanic bombs, p. 736.

3. Assorting of Fragmental Material. — (1.) By variations in the rate of flow of waters, p. 654.

2. Through the unequal wear of harder and softer grains, under the action of the waves or running water, the softer being worn first and drifted off, and so leaving the harder behind, as in the making of a sand-beach, p. 655.

3. By the action of the winds.

4. Transportation of Fragmental Material. — 1. By fresh or salt water, pp. 653, 677.

2. By ordinary floating ice, icebergs, or glaciers, pp. 538, 698, 701.

3. By the winds, pp. 631, 632.

4. By means of migrating animals, p. 607.

5. By the help of floating logs or living plants, p. 607.

5. Deposition and Arrangement in Beds of Fragmental Material. — 1. By winds, p. 631.

2. By fresh waters in their ordinary condition, or during occasional or annual floods, pp. 654, 658.

3. By fresh waters in a prolonged flood, producing till, p. 546.

4. By a plunging flow of waters, pp. 546, 685.

5. By marine waters, p. 680.

6. By glaciers or icebergs, p. 698.

6. Organic Contributions to Fragmental and other Deposits. — 1. Of a Calcareous nature, pp. 59, 60, 135, 615, 707.

2. Of a Siliceous nature, pp. 59, 60, 135, 708.

3. Of Excrementitious origin, or phosphatic, pp. 59, 60, 613.

4. Of Carbonaceous character, pp. 60, 61, 612, 616.

7. Colors of Fragmental Deposits, Limestone included. — 1. *Brownish-yellow to brown colors due to limonite, the hydrous oxyd of iron,* $Fe^2O^3 + 1\frac{1}{2}HO$. (1.) The limonite derived directly from the oxydation attending the disintegration by which the sands were made, the sands having not been subjected afterward to washing on a seashore, which removes such iron-oxyd.

(2.) The limonite deposited in a low wet region, where the fragmental deposit was in process of accumulation; not a possible result in an open estuary or on an open coast, p. 710.

(3.) The limonite produced by the action of ordinary waters on a deposit, pervious to water, containing an iron-bearing mineral, p. 710.

2. *Brownish yellow or brown color, due to the hydrous iron-silicate, palagonite.* This mineral is formed when a bed of volcanic cinders or granulated volcanic rock is subjected to the action of warm waters, the pyroxene of the material being altered, by losing part of its silica, having its iron changed to the sesquioxyd state, and taking in water.

3. *Green, Brownish-green, or Olive-green color, due to the hydrous iron-silicate, glauconite.* — The silica in glauconite, the green mineral giving the color to the *green-sand* of the Cretaceous and other formations, is supposed to come from the siliceous secretions of minute Sponges in the cellules of Rhizopods, etc.: but the process of formation is not understood.

4. *Red color, due to red oxyd of iron,* Fe^2O^3. — (1) From the heating of beds containing limonite as the coloring material, limonite becoming the red oxyd when heated, p. 764.

(2.) From the oxydation of the iron of an iron-bearing mineral through the action of moisture and heat, pp. 711, 764.

(3.) The same as (2), at the ordinary temperature in dry warm regions.

5. *Black and Brownish-black colors.* — (1.) From the presence of carbonaceous substances, derived from vegetable or animal matters; in which case the rock will burn white.

(2.) From the presence of an oxyd of iron; in which case the rock will burn red.

(3.) From the presence of an oxyd of manganese; in which case the rock will remain black or bluish-black, on heating.

6. *Mottled Coloring.* — 1. Rocks colored red or brownish-red, with oxyd of iron, become mottled, through the deoxydation of the iron, by means of waters containing organic matters: the waters often pass through loose sandy beds without altering them, and then reach a clayey layer where they spread and make the changes, p. 710.

7. *External colors due to vegetation.* — Minute black, brownish-black, and greenish-gray lichens give an external coloring to rocks, which is often mistaken for their true colors. Outcrops of granular limestone, a white rock, are usually quite black, from the species with which they are overgrown. Larger lichens sometimes spread over the surfaces of rocks, and give them a mottled aspect.

NOTE. — The above observations on the colors of fragmental rocks apply to the decomposed crusts of crystalline rocks, and to some extent to the crystalline rocks themselves. Red, as a color of rocks, always comes from traces of the red oxyd of iron; green is usually owing to disseminated chlorite, but sometimes to serpentine, pyroxene, or hornblende; and black and greenish-black to iron-bearing varieties of hornblende, pyroxene, or mica.

Granular limestone or marble has often been mottled and veined through an extensive fracturing and then a displacement of the pieces, and the subsequent filling of the intervals between the pieces with a deposit of white or colored carbonate of lime. Another style of mottling or clouding in marble is due to the distribution of impurities, the impurities of the original limestone having received a crystallized condition and agreeable colors (being converted into crystalline minerals), during the metamorphism of the rock.

9. Consolidation of Fragmental Deposits.

1. Through siliceous solutions, pp. 708, 755.
2. Through calcareous solutions, p. 707.
3. Through the production of an oxyd or silicate of iron, by one of the methods mentioned under section 7. See also p. 710.
4. Through infiltration of phosphates into calcareous beds, from overlying guano.
5. By pressure of superincumbent beds, which alone is ineffectual in the case of sand-beds, but may produce some effect with clayey deposits.
6. Through metamorphism, p. 755.

II. Crystalline Texture of Rocks.

1. Through metamorphism, pp. 63, 756, 757.
2. On cooling, from more or less perfect fusion, p. 63.
3. On depositions from solution, p. 63. (In the case of the opal depositions from hot springs, p. 719, it is questioned whether there is a crystalline texture.)
4. On passing to the solid state, at the time when made by chemical means, as in the case of beds of gypsum, made from action of sulphuric acid on limestone, p. 234.

III. Fractures.

1. By lateral pressure. — 1. Experimental trials, p. 801.

2. The lateral pressure resulting from the contraction of the crust on cooling, p. 790.

3. The lateral pressure produced by change of temperature in rocks, p. 720.

2. By contraction. — 1. Through cooling, producing sometimes a columnar structure, pp. 112, 721.

2. By drying, producing sometimes columnar fractures, pp. 84, 721.

3. By means of foreign substances in crevices or openings. —

1. The growth of vegetation, p. 607.

2. Water freezing, p. 687.

3. Chemical change in the crevice, developing an oxyd of iron or some other mineral, and so prying open and deepening it.

4. The ice of the bottom of a moving glacier, p. 538.

4. By the action of gravity. — Takes place after an undermining, or a loosening in some way, pp. 651, 665, 728, 731.

5. By vapors suddenly developed, p. 738.

IV. Flexures.

1. By lateral pressure. — 1. The lateral pressure from the earth's contraction on cooling, pp. 785, 798.

2. The lateral pressure from the expansion of rocks by heat.

3. The lateral pressure due to the action of gravity, pp. 666, 814.

2. Through upward pressure. — 1. By means of steam or expanding vapors, as in volcanic regions, producing oven-shaped prominences over lava currents, and bulgings in areas of solid beds of rock, p. 747.

2. By means of a forced rising of the melted rock of a conduit or fissure, acting on adjoining or overlying beds, pp. 747, 824.[1]

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[1] In the case of the Henry Mountains, briefly referred to on page 824, the horizontal strata of the region, for a thickness of at least 10,000 feet, according to Mr. G. K. Gilbert (who observes that in the era of the eruption, from 3,500 to 7,000 feet of Tertiary probably covered the Cretaceous formation), were bulged upward, in consequence of the intrusion below of melted porphyritic trachyte, into round-topped elevations (or groups of such elevations), rising abruptly out of the plateau to a height, in some instances, of 5,000 feet. The dip about the sides is often 45° and in some cases even 80°. Around and between them the region is a flat plain. If the facts are correctly interpreted by the able geologist who reports them, these are examples of the flexing of strata into mountain domes by an upward flowing lava-stream.

Since the conclusions have great geological importance, some additional explanations are here given from Mr. Gilbert's Report. (The Report bears the date 1877, but was not issued until October, 1879, after the preceding pages of this volume were in type.) Fig. 1160 is an ideal section of the bulged strata with the underlying laccolith. The laccolith, as is seen, rests on *horizontal* strata; and this has been observed to be their actual position in several cases. The thickness, or height, is sometimes over 3,000 feet, and the breadth is, on an average, seven times the height, but in one case, only three times. Traces of three or four lines of bedding sometimes exist, indicating an intermittent flow in the lava. From the laccolith, rise dikes of trachyte — which, however, are generally much more numerous than might be inferred from the figure, and often pass up between layers of the overlying beds. The sandstone adjoining the trachytic mass, both above and below it and bordering the dikes, is usually more or less altered by the heat to the thickness of a foot or more. Erosion has reduced the original domes to deeply gorged mountain peaks and ridges, and in some of them has exposed part of the interior laccolith, so as to show its original surface, while in one the whole stands bare and waterworn. The chamber occupied by the laccolith was in all cases made along a shaly layer in the formation where the cohesion was least. They occur at different levels in the strata, and the one lowest in geological position is 4,500 feet below the level of the highest; the former is between Carboniferous beds, and the latter between Cretaceous.

Fig. 1160.

Ideal Section of a Laccolith. From Gilbert.

It follows from the conditions represented that the propelling action upon the lava, in the deep regions whence it came, was so powerful that in spite of friction along the passage and the density of the lavas (at least 2·33), they were thrown for an unknown number of miles up to the laccolith level; and then had energy enough left to lift, in the case of the laccolith lowest in geological level, a mass of beds 10,000 feet or more thick and 2·25 in average specific gravity (equivalent in pressure to 675 atmospheres) to a height of 5,000 feet. Some accession to the force, however, may have come from vapors derived from subterranean moisture or waters encountered on the way up. As Mr. Gilbert states, the intrusion of the lava laterally into a chamber widened the area of pressure, and thus enabled it, on the principle of the hydraulic press, to accomplish the lift.

The author adds to Mr. Gilbert's explanations that, with so powerful a flow, the lavas

3. Through the conditions of cooling. — Want of parallelism in the opposite cooling surfaces of cooled rock, making curved columns in some igneous rocks, p. 721.

4. By gravity. — Acting on a mass supported only at the sides, p. 695.

V. Veins.

Pages 108 to 114, 770 to 782.

VI. Elevations. Mountains.

1. By Lateral Pressure. — 1. The lateral pressure from the Earth's contraction on cooling, producing geanticlinals and geosynclinals, p. 817.

2. The same, producing a synclinorium or an anticlinorium, p. 821.

3. The same, resulting in fractures and monoclinal uplifts, p. 818.

4. The lateral pressure, produced by expansion from heat, received from a region of liquid rock or otherwise.

5. The lateral pressure produced by the gravity of an adjoining uplifted region or mass.

2. By Upward Pressure. — 1 and 2 as under IV.

3. Upward pressure from accessions of heat to underlying rocks, p. 811.

3. By circumdenudation. — Produced by denudation over a region of nearly horizontal rocks, pp. 647, 652, 822.

4. Apparent elevation due to a sinking of the Water-level. — 1. In consequence of a sinking of the ocean's bottom, p. 784.

2. In consequence of the abstraction of water in the making of rocks, p. 668.

3 In consequence of the abstraction of water to make ice over the land, as in the Glacial period, p. 784.

VII. Subsidences.

1 and 2. As under VI.

3. By contraction beneath from cooling, pp. 721, 821.

4. By undermining, through subterranean streams, p. 665.

5. By undermining, through volcanic action, p. 728.

6. Through contraction from the drying of an underlying bed, as, when a portion of a marsh is drained, the surface of that part sinks below the rest.

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would have reached to the top of the fissures whether these terminated in the strata or opened to the surface. It seems probable that the eruptions began in the making, through subterranean movements, and the filling with lava, of a net-work of fissures, which, for the most part, did not extend to the surface. The fissures remained open along their intersections after they had cooled elsewhere, and thus originated the localized conduits for the different laccoliths. Trachyte was an especially favorable material for such results, since it is one of the least fusible of lavas, and hence thickens quickly and deeply when the temperature falls. Its rapid cooling would tend to limit the lateral flow of the lavas in the opened chambers, and give it a confining boundary, and so aid in producing the thick form of the laccolith (much like that of a trachyte dome of some subaerial eruptions), and also prevent the loss of energy from indefinite lateral flow. The term *laccolith* (like *monolith* in form) is substituted above for *laccolite* because the termination *ite* signifies a *kind* of mineral or rock.

Such facts point to the conclusion that a like amount of force may have existed in other fissure lava-streams, and have been the occasion of the vast extent of many igneous outpourings. They have also an important bearing on the question as to the origin of the ejecting force in non-volcanic igneous eruptions. (See p. 747). As has been suggested by LeConte, a large part of the rock material in many great volcanic mountains of the world may have been poured out at the first opening of the vent.

VIII. Valleys.

1. By Erosion. — 1. Through fresh-water streams, this is the great source of the valleys and gorges in mountainous regions: sometimes, though seldom, the direction is predetermined by fractures, p. 641.

2. Through marine currents and waves, removing dikes that intersect coast rocks, or portions of yielding rock; a process which produces small cuts or excavations, but not true valleys, p. 686.

3. Through the action of glaciers, either by the tearing action of the ice, where descending at bottom into cavities in the rocks, or by abrasion carried on by means of the stones in the bottom and sides of the glaciers, p. 539.

2. By movements of the Earth's crust. — 1. Producing parallel ranges of mountains of which the "Mississippi valley" is an example, pp. 23, 825.

2. Producing monoclinal uplifts, and consequently intervening depressions, p. 792.

See further, pp. 824, 825.

IX. Lake Basins.

1. Through glacial action, the glacier plowing deep where the rocks are soft, and so making a deep depression, and then ceasing the excavation where there is a change to a hard rock, p. 539.

2. Through a dam thrown across a valley, by (1) a moraine from a glacier, p. 701; (2) a slide of gravel, or avalanche; (3) a flow of lava; or (4), of a temporary character, through damming by a glacier.

3. Through a dam or dike of sand or gravel made along a seashore, by the waves and tidal currents, shutting off a region of water from connection with the sea, which may finally become fresh, if it receives the drainage of the back country.

4. Through uplifts of mountains surrounding intervales or low plains, for which subsequent erosion provides no complete drainage.

5. Through the elevation of a country producing level regions, over which depressions remain without a drainage channel, because the waters are too sluggish in movement for much erosion, as about the headwaters of the Mississippi.

6. Through the undermining of the surface deposits of a country by the action of water, p. 665.

7. Through the ejection of lavas from a volcano, leaving, when the volcano becomes extinct, a crater as a basin-like depression.

8. Through the contraction of the rocks beneath a region, in consequence of cooling, causing a depression of the surface.

9. Through pressure of overlying beds or of a glacier mass forcing out a softened stratum underneath, p. 666.

X. Markings on Rocks.

1. Scratches. — 1. By the movement of glaciers, pp. 538, 699; or of icebergs, p. 701; or of any floating ice, carrying stones at bottom.

2. By the mutual friction of the opposite walls of a fissure, at the time of the making of the fissure (the usual way), or afterward, pp. 90, 774.

3. By the sliding of beds on one another, either as a consequence of gravity, p. 666, or of lateral pressure, p. 90.

4. By the drifting of sands by winds, pp. 91, 631.

5. Through the rapid transportation of stones by water.

6. By land slides.

2. Other markings. — 1. Ripple-marks, rill-marks, rain-drop impressions, p. 84.

2. Of organic origin, as footprints, etc.

XI. Igneous Action. Earthquakes.

Pages, 722, 804.

XII. Change of Temperature. Sources of Heat.

1. Transformation of motion into heat. — 1. By movements in strata; an important source in metamorphism, pp. 719, 762, 822.

2. By means of movements in water or air, as in the breaking of waves on a rocky coast; very feeble in its action, if at all appreciable, unless in warming slightly the atmosphere.

2. The Earth's interior heat. — 1. Through escape outward from the earth's interior, p. 716.

2. Through convection upward into strata, or "a rise of the isogeothermals," in consequence of the accumulation of sedimentary beds at surface, pp. 718, 762, 820.

3. Through convection from masses or dikes of fused rock into the adjoining rocks.

3. Chemical change, p. 719.

4. The Sun, p. 714.

XIII. Secular Variations in Climate.

1. Through change in amount of heat given out by the sun, p. 716.
2. Through the escape outward of the earth's interior heat, p. 718.
3. Through a secular change in the density of the atmosphere, that is, in the amount of carbonic acid, moisture, etc., pp. 353, 716.
4. Through changes in the amount, position, and height of lands over the earth, pp. 44, 541.
5. Through changes in the courses of oceanic currents, pp. 541, 712.
6. Through variations in the eccentricity of the earth's orbit, p. 714.

XIV. Origin of Continents and Oceanic Basins.

Page 797.

XV. Extinction of Species.

The ordinary effects of nearly all the following causes of extinction are simply destruction of life. But they may also occasion extinction of species.

I. *Catastrophic Causes, not Climatal.*

1. Through the emergence of a region, with its aquatic life.
2. Through the submergence of a region, with its terrestrial life.
3. Through a change in the level of wave action, or in the relations of a sea to currents, these bearing detritus or not.
4. Through a change of salt-water seas or lagoons to fresh-water, and the reverse, p. 610.
5. Through the partial or complete evaporation of salt-water seas or lagoons.
6. Through earthquake-waves.
7. Through the heating of the ocean's waters by means of extensive igneous eruptions, or through the flooding of the land by such eruptions; effectual for volcanic islands, but hardly for wide continental or oceanic areas.

II. *Climatal Causes.*

8. Through the change of level of an emerged region, changing its climate as to its range of temperature, moisture, etc., or as to the excesses of that range.

9. Through the change of level of a submerged oceanic region, changing thereby its relations to warm and cold oceanic currents.

10. Through changes of level in the land, giving a changed direction to the cold or warm oceanic currents, and affecting thus oceanic temperature, and also the temperature of atmospheric currents.

11. Through terrestial or cosmical changes, occasioning an era of great cold for a hemisphere, or for both hemispheres, thereby giving greater cold to oceanic as well as to atmospheric currents, p. 715.

11. Through climatal excesses as to heat and cold, moisture and drought, such as occur, under unchanged conditions of level, once or so in a century.

13. Through the gradual change of climate over the globe, consequent on the earth's secular refrigeration.

III. *Causes of Extinction depending on the Mutual Relations of Species.*

14. Through a loss of the proper food, occasioned by destructions of species, according to any of the above or other methods.

15. Through the excessive multiplication of the natural enemies of the individuals of any species.

16. Through the excessive multiplication of individuals of a species, so that food fails and famine ensues.

These and other related causes have been ably discussed by Darwin.

IV. *Causes of Extinction depending on the Successional Relations of Species.*

17. Through whatever means — the above or others — that may have sufficed, with the lapse of time, to produce changes in the specific characters of species: in other words, through progress in the evolution — however carried forward — of the systems of life.

COSMOGONY.

THE science of cosmogony treats of the history of creation.

Geology comprises that later portion of the history which is within the range of direct investigation, beginning with the rock-covered globe, and gathering only a few hints as to a previous state of igneous fluidity.

Through Astronomy, our knowledge of this earlier state becomes less doubtful, and we even discover evidence of a period still more remote. Ascertaining thence that the sun of our system is in intense ignition, that the moon, the earth's satellite, was once a globe of fire, but is now cooled and covered with extinct craters, and that space is filled with burning suns, — and learning also from physical science that all heated bodies in space must have been losing heat through past time, the smallest most rapidly, — we safely conclude that the earth has passed through a stage of igneous fluidity.

Again, as to the remoter period: the forms of the nebulæ and of other starry systems in the heavens, and the relations which subsist between the spheres in our own system, have been found to be such as would have resulted if the whole universe had been evolved from an original nebula, or gaseous fluid. It is not necessary for the strength of this argument that any portion of the primal nebula should exist now, at this late period in the history of the universe; it is only what might have been expected, that the so-called nebulæ of the present heavens should be turning out to be clusters of stars. If, then, this nebular theory be true, the universe has been developed from a primal unit; and the earth is one of the individual orbs produced in the course of its evolution. The history of the universe is in kind like that which has been deciphered with regard to the earth: it only carries the action of physical forces, under a sustaining and directing hand, farther back in time.

The science of Chemistry also is aiding in the study of the earth's earliest development, and is preparing itself to write a history of the various changes which should have taken place among the elements, from the first commencement of combination to the formation of the solid crust of our globe.

It is not proposed to enter in this place into either chemical or as-

tronomical details, but, assuming the nebular theory to be true, briefly to mention the great stages of progress in the history of the earth, or those successive periods in time which stand out prominently through the exhibition of some new idea in the grand system of progress. The views here offered, and the following on the cosmogony of the Bible, are essentially those brought out by Professor Guyot, in his lectures.

Stages of Progress. — These stages of progress are the following: —

(1.) *The* BEGINNING OF ACTIVITY IN MATTER. — In such a beginning the activity would show itself instantly, by a manifestation of light, since light is a resultant of molecular activity. A flash of light through the universe would therefore be the first announcement of the work begun.

(2.) *The development of the* EARTH. — A dividing and subdividing of the original fluid, carried forward, would ultimately have evolved systems of various grades, and ultimately the orbs of space, among these the EARTH, an igneous sphere enveloped in vapors.

(3.) *The production of the* EARTH'S PHYSICAL FEATURES, by the outlining of the continents and oceans. The condensible vapors would have gradually settled upon the earth, as cooling progressed.

(4.) *The introduction of* LIFE, — in the first existence of the lowest of plants, and of Protozoans among animals. In these simplest forms of living beings, the *systems of structure* characterizing the Animal kingdom, the *Radiate*, *Molluscan*, *Articulate*, and *Vertebrate*, are not clearly pronounced.

(5.) *The display of the* SYSTEMS *in the Kingdoms of Life*, — the exhibition of the four grand types under the Animal kingdom, being the predominant idea in this phase of progress.

(6.) *The introduction of the highest class of Vertebrates, — that of* MAMMALS, the class to which MAN belongs, — eminent above all other Vertebrates for a quality prophetic of a high moral purpose, — that of suckling their young.

(7.) *The introduction of* MAN, — the first being gifted with moral qualities and high reason, and one in whom the unity of nature has its full expression.

There is another great event in the Earth's history which has not yet been mentioned, because of the uncertainty with regard to its exact place among the others. The event referred to is the first shining of the sun upon the earth, after the vapors, which till then had shrouded the sphere, were mostly condensed. This must have preceded the introduction of the Animal system, since the sun is the grand source of activity throughout nature on the earth, and is essential to the existence of life, excepting its lower forms. In the history of the globe, which has been given on page 146, it has been shown that the

outlining of the continents was one of the earliest events, dating even from Archæan time; and it is probable, from the facts stated, that it preceded that clearing of the atmosphere which opened the sky to the earth. This would place the event between numbers 3 and 5, and, as the sun's light was not essential to the earliest of organisms, probably after number 4.

The order, in the history, will then be —

(1.) Activity begun, — light an immediate result.

(2.) The earth made an independent sphere.

(3.) Outlining of the land and water, determining the earth's general configuration.

(4.) The idea of life expressed in the lowest plants, and afterward, if not contemporaneously, in the lowest or systemless animals, the Protozoans.

(5.) The energizing light of the sun shining on the earth, — an essential preliminary to the display of the systems of life.

(6.) Introduction of the systems of life.

(7.) Introduction of Mammals, — the highest of Vertebrates, — the class afterward to be dignified by including a being of moral and intellectual nature.

(8.) Introduction of Man.

Cosmogony of the Bible. — There is one ancient document on cosmogony — that of the opening page of the Bible — which is not only admired for its sublimity but is very generally believed to be of divine origin, and which, therefore, demands at least a brief consideration in this place.

In the first place, it may be observed that *this document, if true, is of divine origin.* For no human mind was witness of the events; and no such mind in the early age of the world, unless gifted with superhuman intelligence, could have contrived such a scheme, — would have placed the creation of the sun, the source of light to the earth, so long after the creation of light, even on the *fourth* day, and, what is equally singular, between the creation of plants and that of animals, when so important to both; and none could have reached to the depths of philosophy exhibited in the whole plan.

Again, *If divine, the account must bear marks of human imperfection, since it was communicated through Man.* Ideas suggested to a human mind by the Deity would take shape in that mind according to its range of knowledge, modes of thought, and use of language, unless it were at the same time supernaturally gifted with the profound knowledge and wisdom adequate to their conception; and even then they could not be intelligibly expressed, for want of words to represent them.

The central thought of each step in the Scripture cosmogony — for example, Light; the Dividing of the fluid earth from the fluid around it, individualizing the earth; the Arrangement of its land and water; Vegetation; and so on — is brought out in the simple and natural style of a sublime intellect, wise for its times, but unversed in the depths of science which the future was to reveal. The idea of vegetation to such a one would be vegetation as he knew it; and so it is described. The idea of dividing the earth from the fluid around it would take the form of a dividing from the fluid above, in the imperfect conceptions of a mind unacquainted with the earth's sphericity and the true nature of the firmament, — especially as the event was beyond the reach of all ordinary thought.

Objections are often made to the word "day," — as if its use limited the time of each of the six periods to a day of twenty-four hours. But, in the course of the document, this word "day" has various significations, and, among them, all that are common to it in ordinary language. These are — (1) The light, — "God called the light, day," v. 5; (2) the "evening and the morning" before the appearance of the sun; (3) the "evening and the morning" after the appearance of the sun; (4) the hours of light in the twenty-four hours (as well as the whole twenty-four hours), in verse 14; and (5) in the following chapter, at the commencement of another record of creation, the whole period of creation is called "a day." The proper meaning of "evening and morning," in a history of creation, is *beginning and completion;* and, in this sense, darkness before light is but a common metaphor.

A Deity working in creation, like a day-laborer, by earth-days of twenty-four hours, resting at night, is a belittling conception, and one probably never in the mind of the sacred penman. In the plan of an infinite God, centuries are required for the maturing of some of the plants with which the earth is adorned.

The order of events in the Scripture cosmogony corresponds essentially with that which has been given. There was first a void and formless earth; this was literally true of the "heavens and the earth," if they were in the condition of a gaseous fluid. The succession is as follows: —

(1.) Light.

(2.) The dividing of the waters below from the waters above the earth (the word translated *waters* may mean *fluid*).

(3.) The dividing of the land and water on the earth.

(4.) Vegetation; which Moses, appreciating the philosophical characteristic of the new creation, distinguishing it from previous inorganic substances, defines as that "which has seed in itself."

(5.) The sun, moon, and stars.

(6.) The lower animals, those that swarm in the waters, and the creeping and flying species of the land.

(7.) Beasts of prey ("creeping" here meaning "prowling").

(8.) Man.

In this succession, we observe not merely an order of events, like that deduced from science; there is a system in the arrangement, and

a far-reaching prophecy, to which philosophy could not have attained, however instructed.

The account recognizes in creation two great eras, each of three days, — an *Inorganic* and an *Organic*.

Each of these eras opens with the appearance of *light*: the *first*, light cosmical; the *second*, light from the sun, for the special uses of the earth.

Each era ends in a "day" of *two* great works, — the two shown to be distinct, by being severally pronounced "good." On the *third* "day," that closing the Inorganic era, there was first the *dividing of the land from the waters*, and afterward the *creation of vegetation*, or the institution of a kingdom of life, — a work widely diverse from all preceding it in the era. So, on the *sixth* "day," terminating the Organic era, there was first *the creation of Mammals*, and then a second far greater work, totally new in its grandest element, *the creation of Man.*

The arrangement is, then, as follows: —

1. *The Inorganic Era.*

1st Day. — LIGHT cosmical.

2d Day. — The earth divided from the fluid around it, or individualized.

3d Day. — { 1. Outlining of the land and water.
2. Creation of vegetation.

2. *The Organic Era.*

4th Day. — LIGHT from the sun.

5th Day. — Creation of the lower orders of animals.

6th Day. — { 1. Creation of Mammals.
2. Creation of Man.

In addition, the last day of each era included one work typical of the era, and another related to it in essential points, but also prophetic of the future. Vegetation, while, for physical reasons, a part of the creation of the third day, was also prophetic of the future Organic era, in which the progress of life was the grand characteristic. The record thus accords with the fundamental principle in history that the characteristic of an age has its beginnings within the age preceding. So, again, Man, while like other Mammals in structure, even to the homologies of every bone and muscle, was endowed with a spiritual nature, which looked forward to another era, that of spiritual existence. The *seventh* "day," the day of rest from the work of creation, is Man's period of preparation for that new existence; and it is to

promote this special end that — in strict parellelism — the Sabbath follows man's six days of work.

The record in the Bible is, therefore, profoundly philosophical in the scheme of creation which it presents. It is both true and divine. It is a declaration of authorship, both of Creation, and the Bible, on the first page of the sacred volume.

There can be no real conflict between the two Books of the Great Author. Both are revelations made by Him to Man, — the *earlier* telling of God-made harmonies, coming up from the deep past, and rising to their height when Man appeared, the *later* teaching Man's relations to his Maker, and speaking of loftier harmonies in the eternal future.

APPENDIX.

A. — New Paleozoic, Triassic, and Jurassic Vertebrates, chiefly American.

1. *Devonian, Carboniferous.* — The remains of Corniferous fishes, referred to on page 263, are figured and described by Newberry, along with Carboniferous species, in vol. i. of the Palæontology of Ohio; and vol. ii., of the same series, contains descriptions and figures of other Carboniferous species by Newberry, and of new Amphibians by E. D. Cope. The number of known species of Ohio Amphibians (p. 339) is increased by Cope (from the collections placed in his hands by Newberry) to *thirty-four;* and among them are true Amphibian snakes. *Phlegethontia linearis* resembled a whip-snake in its proportions; *Malgophis macrurus* (to which Cope refers, with a query, Fig. 680, p. 340,) was probably limbless, and nearly of the size of the common rattlesnake. None of the powerfully-armed Labyrinthodonts have been found in North America.

2. *Permian Reptiles.* — The Permian (or Triassic ?) of South Africa, has afforded Prof. Owen, of London, Reptiles having some of the characters of carnivorous Mammals (particularly marked in the canines and incisors) to which he has given the name of *Theriodonts.* One of them, *Cynodraco major*, has the sabre-shaped canines of the Lions of the genus Machærodus. Quart. J. Geol. Soc., 1876.

The Upper Carboniferous of Illinois, near Danville, has afforded some Reptilian remains, which have been described by E. D. Cope, and referred by him to the Permian. See Proc. Amer. Phil. Soc., xvii., 187 and beyond, Nov. 1877. Other species, and some of Amphibians, have been described by the same author from the "Permian formation" of Texas. The species of Illinois and Texas are stated to be about equally related to the types in the Permian of the Urals and the species described by Owen from South Africa. The Reptiles are referred to the *Rhynchocephalia*, and the Amphibians to the *Stegocephali.* With them occur remains of fishes of the genera *Janassa*, *Ctenodus*, and *Diplodus*, which favor the view of a Permian age. Ibid., xvii., 505, April, 1878 (printed May 18).

Marsh has described several species of fossil Reptiles from beds in New Mexico, which he refers to the "Upper Permian." Part "have the more important characters of the Rhynchocephalia, of which the genus *Hatteria*, of New Zealand, is the living type." They occur with the remains of Amphibians and Fishes. *Ophiacodon grandis*, the largest of them yet found, was about 10 feet long, *Nothodon lentus*, 5 or 6 feet, and *Sphenacodon ferox*, about 6 feet. Amer. J. Sci., III., xv., 409, May, 1878 (issued May 1).

A. Gaudry has described Permian Reptiles from Autun, in France. One, *Actinodon*, of Frossard, is stated to be near *Archegosaurus*, and also near *Rhachitomus* of Cope, from Texas; and another, of higher type, named *Euchirosaurus*, is near the *Cynodraco* of Owen and certain of the Texas species described by Cope. Bull. Soc. Géol. de France, III., vii., 62, 1878.

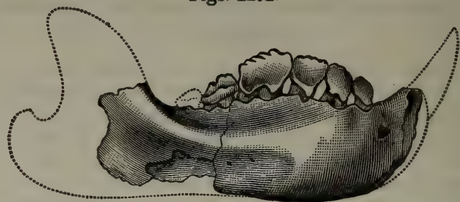
3. *Triassic Reptiles.* — New species of reptiles have been described by E. D. Cope, from the Triassic (or Triassico-Jurassic) of Pennsylvania and North Carolina, in the Proceedings of the American Philosophical Society, vol. xvii., pp. 82, 231, 1877; and from New Mexico, in the Palæontology of Wheeler's Expedition, 1877.

4. *Jurassic Marsupial Mammals.* — Besides the two species of Marsupials mentioned on page 433, Marsh has named and described the following (Amer. J. Sci., III., xviii. 396, 1879): *Dryolestes vorax, D. arcuatus, Tinodon bellus* (Fig. 1110, right lower jaw), *T. robustus, T. lepidus, Ctenacodon serratus* (Fig. 1161, right lower jaw). None of the species is larger than the weasel. *Stylacodon* is near *Stylodon*, of Owen, and *Ctenacodon*, near *Plagiaulax*, of Falconer. Marsh observes that the species are closely related to those of the Purbeck of England (p. 446). The specimens are from a thin bed in the Upper Jurassic of Wyoming, pertaining to the series called by Marsh the Atlantosaurus beds. In underlying beds occur

Fig. 1161.

Tinodon bellus (× 9).

Figs. 1162.



Ctenacodon serratus (× 4).

remains of *toothless* Enaliosaurs, named *Sauranodonts* by Marsh (1879). It is a noteworthy fact that the earliest of American as well as of European mammals are small species.

B. — Catalogue of American Localities of Fossils.

The following catalogue contains some of the more important of American localities of fossils, and is intended for the convenience especially of the student-collector.

Localities of Fossils.

Acadian Group. — Coldbrook, Ratcliffe's Millstream, St. John, N. B.; Long Arm of Canada Bay, Newfoundland.

Potsdam Group. — Swanton, Vt.; Braintree, Mass.; Keeseville (at "High Bridge"), Alexandria, Troy, N. Y.; Chiques Ridge, Pa.; Falls of St. Croix, Osceola Mills, Trempaleau, Wisconsin; Lansing, Iowa; St. Ann's, Isle Perrot, C. W.; near Beauharnois on Lake St. Louis, C. E.

Calciferous. — Mingan Islands, St. Timothy, and near Beauharnois, C. E.; Grand Trunk Railway between Brockville and Prescott, St. Ann's, Isle Perrot, C. W.; Amsterdam, Fort Plain, Canajoharie, Chazy, Lafargeville, Ogdensburg, N. Y.

Quebec Group. — Mingan Islands, Point Levi, Philipsburg, and near Beauharnois, C. E.; Point Rich, Cow Head, Newfoundland; cuts in Black Oak Ridge and Copper Ridge, Knoxville and Ohio Railroad, Tenn.; Malade City, Idaho.

Chazy Limestone. — Chazy, Galway, Westport, N. Y.; one to three miles north of "the Mountain," Island of Montreal, C. E.; St. Joseph's Island, Sault Ste. Marie, C. W.; Knoxville, Lenoir's, Bull's Gap, Kingsport, Tenn.

Bird's-eye Limestone. — Amsterdam, Little Falls, Fort Plain, Adams, Watertown, N. Y.

Black River Limestone. — Watertown, N. Y.; Ottawa, C. W.; Island of Montreal, and near Quebec, C. E.

Trenton Limestone. — Adams, Watertown, Boonville, Turin, Jacksonburg, Little Falls, Lowville, Middleville, Fort Plain, Trenton Falls, N. Y.; Pine Grove, Aaronsburg, Potter's Fort, Milligan's Cove, Pa.; Highgate Springs, Vt.; Montmorency Falls and

Beauport Quarries near Quebec, Island of Montreal (quarries north of the city), C. E.; Ottawa, Belleville, Trenton (G. T. R. R., west of Kingston), C. W.; Copper Bay, Mich.; Elkader Mills, Turkey River, Dubuque, Iowa; Falls of St. Anthony, St. Paul, Mineral Point, Cassville, Beloit, Quimby's Mills near Benton, Wis.; Warren, Rockton, Winslow, Dixon, Freeport, Cedarville, Savanna, Rockford, Illinois; Murfreesborough, Columbia, Lebanon, Tenn.

Utica Slate. — Turin, Martinsburg, Lorraine, Worth, Utica, Cold Spring, Oxtungo and Osquago Creeks near Fort Plain, Mohawk, Rouse's Point, N. Y.; Rideau River along railroad at Ottawa, bed of river two miles above, C. W.

Hudson River Group. — Pulaski, Rome, Lorraine, Boonville, N. Y. — Penn's Valley, Milligan's Cove, Pa. — Oxford, Cincinnati, Lebanon, O. — Madison, Richmond, Ind. — Anticosti, opposite Three Rivers, C. E. — Weston on the Humber River, nine miles west of Toronto, C. W. — Little Makoqueta River, Iowa. — Savannah, Green Bay, Wis. — Thebes, Alexander County; Savanna, Carroll County; Scales' Mound, Jo Daviess County; Oswego, Yorkville, Kendall County; Naperville, Dupage County; Wilmington, Will County, Ill. — Cape Girardeau, Mo. — Drummond's Island, Mich. — Nashville, Columbia, Knoxville, Tenn.

Medina Sandstone. — Lockport, Lewiston, Medina, Rochester, N. Y.; Long Narrows below Lewistown, Pa.; Dundas, C. W.

Clinton Group. — Lewiston, Lockport, Reynolds' Basin, Brockport, Rochester, Wolcott, New Hartford, N. Y.; Thorold on Welland Canal, Hamilton, Ancaster, Dundas, C. W.; Hanover, Ind.

Niagara. — Lewiston, Lockport, Gosport, Rochester, Wolcott, N. Y.; Thorold, Hamilton, Ancaster, C. W.; Anticosti, C. E.; Arisaig, Nova Scotia; Racine, Waukesha, Wis.; Sterling, Grafton, Savanna, Chicago, Joliet, Ill.; Marblehead on Drummond's Island, Michigan; Springfield, Cedarville, Ohio; Delphi, Waldron, Jeffersonville, Madison, Ind.; Louisville, Ky.; the "glades" of West Tennessee. (*Coralline Limestone.* — Schoharie, N. Y.)

Onondaga Salt Group. — Buffalo, Williamsville, Waterville, Jerusalem Hill (Herkimer County), N. Y.; Galt, Guelph (G. T. R. R.), C. W.

Lower Helderberg Limestones. — Dry Hill, Jerusalem Hill (Herkimer County), Sharon, East Cobleskill, Judd's Falls, Cherry Valley, Carlisle, Schoharie, Clarksville, Athens, N. Y.; Pembroke, Parlin Pond, Me.; Gaspé, C. E.: Arisaig, East River, Nova Scotia; Peach Point, opposite Gibraltar, Ohio; Thebes, Devil's Backbone, Ill.; Bailey's Landing, Mo.; "glades" of Wayne and Hardin Counties, Tenn.

Oriskany Sandstone. — Oriskany, Vienna, Carlisle, Schoharie, Pucker Street, Catskill Mountains, N. Y.; Cumberland, Md.; Moorestown and Frankstown, Pa.; Bald Bluffs, Jackson County, Ill., four miles S. W. of St. Mary's, Ste. Genevieve County, Mo.

Cauda-galli Grit. — Schoharie (Fucoides Cauda-galli), N. Y.

Schoharie Grit. — Schoharie, Cherry Valley, N. Y.

Upper Helderberg Limestones. — Black Rock, Buffalo, Williamsville, Lancaster, Clarence Hollow, Stafford, Le Roy, Caledonia, Mendon, Auburn, Onondaga, Cassville, Babcock's Hill, Schoharie, Cherry Valley, Clarksville, N. Y.; Port Colborne, and near Cayuga, C. W.; Columbus, Delaware, White Sulphur Springs, Sandusky, Ohio; Mackinac, Little Traverse Bay, Dundee, Monguagon, Mich.; North Vernon, Charlestown, Kent, Hanover, Jeffersonville, Ind.; Louisville, Ky.

Marcellus Shales. — Lake Erie shore, ten miles S. of Buffalo, Lancaster, Alden, Avon, Leroy, Marcellus, Manlius, Cherry Valley, N. Y.

Hamilton Group. — Lake Erie shore, Eighteen Mile Creek, Hamburg, Alden, Darien, York, Moscow, East Bethany, Bloomfield, Bristol, Seneca Lake, Cayuga Lake, Skaneateles Lake, Moravia, Pompey, Cazenovia, Delphi, Bridgewater, Richland, Cherry Valley, Seward, Westford, Milford, Portlandville, N. Y.; Widder Station (G. T. R. R.), near Port Sarnia, C. W.; New Buffalo, Independence, Rockford, Iowa; Devil's Bake Oven, Jackson County, Moline, Rock Island, Ill.; Grand Tower, Mo.; Thunder Bay, Little Traverse Bay, Mich.; Nictaux, Bear River, Moose River, Nova Scotia.

Genesee Slate. — Banks of Seneca and Cayuga Lakes, Lodi Falls, Mount Morris, two miles south of Big Stream Point, Yates County, N. Y.

Portage Group. — Eighteen Mile Creek on Lake Erie Shore, Chautauqua Lake, Genesee River at Portage, Flint Creek, Cashaqua Creek, Nunda, Seneca and Cayuga Lakes, N. Y.; Delaware, Ohio; Rockford, North Vernon, Ind.; Danville, Ky.

Chemung Group. — Rockville, Philipsburg, Jasper, Greene, Chemung Narrows, Troopsville, Elmira, Ithaca, Waverly, Hector, Enfield, Franklin, N. Y.; Gaspé, C. E.

Catskill Group. — Fossils rare. — Richmond's quarry above Mount Upton on the Unadilla, Oneonta, Oxford, Steuben County, south of the Canisteo, N. Y.

Subcarboniferous. — Burlington, Keokuk, Columbus, Iowa; Quincy, Warsaw, Alton, Kaskaskia, Chester, Ill.; Crawfordsville, Greencastle, Bloomington, Spergen Hill, New Providence, Ind.; Hannibal, St. Genevieve, St. Louis, Mo.; Willow Creek, Battle Creek, Marshal, Moscow, Jonesville, Holland, Grand Rapids, Mich.; Mauch Chunk, Pa.; Newtonville, Ohio; Ice's Ferry, on Cheat River, Monongalia County, W. Va.; Red Sulphur Springs, Pittsburg Landing. White's Creek Springs, Waynesville, Cowan, Tenn.; Big Bear and Little Bear Creeks, Big Crippled Deer Creek, Miss.; Clarksville, Huntsville, Ala.; Windsor, Horton, Nova Scotia.

Carboniferous. — South Joggins, Pictou, Sydney, Nova Scotia. — Wilkesbarre, Shamokin, Tamaqua, Pottsville, Minersville, Tremont, Greensburg, Carbondale, Port Carbon, Lehigh, Trevorton, Johnstown, Pittsburg, Pa. — Pomeroy, Marietta, Zanesville, Cuyahoga Falls, Athens, Yellow Creek, Ohio. — Charlestown, Clarksburg, Kanawha, Salines, Wheeling, W. Va. — Saline Company's Mines, Gallatin County; Carlinville, Hodges Creek, Macoupin County; Colchester, McDonough County; Duquoin, Perry County; Murphysborough, Jackson County; Lasalle; Morris, Mazon and Waupecan Creeks, Grundy County; Danville, Pettys' Fo.d, Vermilion County; Paris, Edgar County; Springfield, Ill. — Perrysville, Eugene, Newport, Horseshoe of Little Vermillion, Vermillion County; Durkee's Ferry, near Terre Haute, Vigo County; Lodi, Parke County; Merom, Sullivan County, Ind. — Bell's, Casey's and Union Mines, Crittenden County; Hawesville and Lewisport, Hancock County; Breckenridge, Giger's Hill, Mulford's Mines, and Thompson's Mine, Union County; Providence and Madisonville, Hopkins County; Bonharbour, Daviess County, Ky. — Muscatine, Alpine Dam, Iowa. — Leavenworth, Indian Creek, Grasshopper Creek, Juniata, Manhattan, Kansas. — Rockwood, Emory Mines, Coal Creek, Careyville, Tenn. — Tuscaloosa, Ala.

Triassic. — Southbury, Middlefield, Portland, Conn.; Turner's Falls, Sunderland, Mass.; Phœnixville, Pa.; Richmond, Va.; Deep River and Dan River Coal-fields, N. C.

Cretaceous. — Upper Freehold, Middletown, Marlborough, Blue Ball, Monmouth County, Pemberton, Vincenton, Burlington County, Blackwoodtown, Camden County, Mullica Hill, Gloucester County, Woodstown, Mannington, Salem County, New Egypt, Ocean County, N. J. — Warren's Mill, Itawamba County, Tishomingo Creek, R. R. cuts, Hare's Mill, Carrollsville, Tishomingo County, Plymouth Bluff, Lowndes County, Chawalla Station (M. & C. R. R.), Ripley, Tippah County, Noxubee, Macon, Noxubee County, Kemper, Pontotoc and Chickasaw Counties, Miss. — Finch's Ferry, Prairie Bluff, on Alabama River; Choctaw Bluff, on Black Warrior River; Greene, Marengo, and Lowndes Counties, Ala. — Fox Hills, Sage Creek, Long Lake, Great Bend, Cheyenne River, etc., Nebraska. — Fort Harker, Fort Hayes, Fort Wallace, Kansas. — Fort Lyon, Santa Fé, New Mexico.

Eocene. — Everywhere in Tippah County; Yockeney River; New Prospect P. O., Winston County; Marion, Lauderdale County; Enterprise, Clarke County; Jackson; Satartia, Yazoo County; Homewood, Scott County; Chickasawhay River, Clarke County; Winchester, Red Bluff Station, Wayne County; Vicksburg, Amsterdam, Brownsville, Warren County; Brandon, Byram Station, Rankin County; Paulding, Jasper County, Miss. — Claiborne, Monroe County, St. Stephen's, Washington County, Ala. — Charleston, S. C. — Tampa Bay, Florida. — Fort Washington, Fort Marlborough, Piscataway, Md. — Marlbourne, Va. — Brandon, Vt. — In New Jersey, at Farmingdale, Squankum and Shark River, Monmouth Co. — Green River, Fort Bridges, Wyoming. — Cañada de las Uvas, Cal.

Miocene. — Gay Head, Martha's Vineyard, Mass.; Shiloh, Jericho, Cumberland County, and Deal, Monmouth Co., N. J.; St. Mary's, Easton, Md.; Yorktown, Suffolk, Smithfield, Richmond, Petersburg, Va.; Astoria, Willamette Valley, John Day Valley, Oregon; San Pablo Bay, Ocoya Creek, San Diego, Monterey, San Joaquin and Tulare Valleys, Cal.; White River, Upper Missouri Region; Crow Creek, Colorado.

Pliocene. — Ashley and Santee Rivers, S. C.; Platte and Niobrara Rivers, Upper Missouri; John Day Valley, Oregon; Sinker Creek, Idaho; Alameda County, Cal.

C. — Brief Synopsis of this Manual.

This synopsis is intended to serve as a basis for a short course of instruction, such as may be desired in Institutions not strictly scientific.

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The following are the authorities for the more important illustrations of this Manual. The works mentioned are those from which the figures or views have been taken; and, although generally the original publications, they are not all so. When the figures have been made from original drawings not before published (the fact with regard to about 150), the reference in distinguished by annexing a point of interjection (!). Many of the new figures by Meek under the Mesozoic and Cenozoic, are from a manuscript Paleontological Report of Lieut. G. K. Warren's Expedition to the Upper Missouri, by Messrs. Meek and Hayden.

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	612 A	Hall.
310	613!	Lesley.
312	614	Dawson.
317	615 *a, b, c*	Bailey.
	616	Dawson.
322	617!	Russell Smith.
324	619	H. L. Fairchild.
	620, 621, 623, 624	Lesquereux.
	622	Bronn.
325	625–627	Newberry.
	628, 629	Lesquereux.
326	630–632	Lesquereux.
	633	Brongniart.
327	634–640	Lesquereux.
	641	Brongniart.
328	642 *a, c*	Newberry.
	642 *b*	Dawson.
	643	J. D. Hooker.
329	644–646 A	Newberry.
332	646!	Meek.
	647	Hall.
	648–650!	Meek.
	651	Cox.
	652!	Meek.
333	653, 655–657	Hall.
	654	Koninck.
	658	Dawson.
	659, 660	Bradley.
	661	Dawson.
	662	Meek & Worthen.
334	663–665, 667, 668	Meek & Worthen.
	666	Dawson.
	668 A!	J. H. Emerton (for Harger).
335	669	Author.
	670	Scudder.
	671	Lesquereux.
336	673, 674	Newberry.
	675, 677	Newberry & Worthen.
	676!	Bradley.
340	678	Cope.
	679, 680	Wyman.
	681	Marsh.
344	681 A	Ramsay.
350	682, 684, 685	Bronn.
	683	Murchison.
	686	Vogt.
	686 A	Salter.
368	687–691!	Meek.
370	692–695	Geinitz.
371	696	Murchison.
373	697	Von Meyer.
374	698!	Author.
396	699	Taylor.
	700	H. D. Rogers.
	701	Lesley.
	702	H. D. & W. B. Rogers.
397	703!	Lesley

PAGE	FIG.	
641	1076, 1077	Author.
644	1078 !	Holmes.
645	1079 !	Powell's Exped. photograph.
646	1080	Ives.
651	1081, 1082	Lesley.
652	1083–1092	Lesley.
659	1092	U. S. Coast Survey.
661	1093	Richthofen.
666	1095	Vanuxem.
677	1096, 1097	Author.
681	1098 !	J. D. Hague.
690	1100 !	Guyot (in part).
	1101–1104	Tyndall.
690	1105	Agassiz.
700	1106	Holmes.
708	1108	Photograph by Jackson.
724	1110	Author.
725	1111, 1112	Author.
726	1113–1115	Author.
730	1116	Author.
	1117 !	Coan and Judd.
735	1118	Photograph by Watkins.
740	1119	Author.
741	1120	J. D. Whitney.
742	1121	Holmes.
750	1123–1125	Photographs by Jackson.
751	1126	Holmes.
752	1127	Photograph.
772	1129	De la Beche.
773	1130, 1131	De la Beche.
779	1132, 1133	Crouch.
786	1134	J. L. Campbell.
787	1136–1141	Author.
788	1142	Author.
789	1143	Holmes, Gardner.
790	1144	J. M. Safford.
792	1145	Powell.
793	1146, 1147	Powell.
	1148–1150	Heim.
794	1150 A !	Author.
799	1151, 1152	Townsend.
801	1153–1156	Daubrée.
802	1157	Daubrée.
803	1158	Daubrée.
840	1160	G. K. Gilbert.
852	1161, 1162	Marsh.

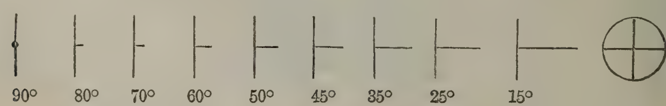
The Plates 1 to 12 are all from O. C. Marsh. The Physiographic Chart is by the Author, excepting the Topography of the Continents by A. Guyot. The dark lines over the dark-shaded parts of the Continents indicate the courses of mountain ranges or chains. The dotted lines crossing the oceanic areas are isothermal lines, passing through points having the same mean temperature for the coldest month of the year (and hence called *isocrymes*), and the number attached to each marks the mean temperature in Fahrenheit degrees. The line A A crossing the Pacific Ocean obliquely gives the direction of the longer axis of the Pacific Ocean; and B B in the North Atlantic Ocean, the same for that ocean. The line A′ A′ in the Pacific is the axis of the area that was affected by the Coral-island subsidence.

The oceanic zone between the isothermal lines (or isocrymes) of 68° F., which is colored pale yellow, is that over which the temperature is favorable for the growth of reef-forming corals; and outside of it the temperature excludes them.

F. — Suggestions for the Working Geologist.

1. *Diagrams of Sections.* — Uniformity in the mode of representing the several kinds of rocks in diagrams of sections, would avoid the necessity of explaining that this part stands for *sandstone*, that for *limestone*, and so on. The modes exemplified in the section on page 102 have the advantage of being simple and self-explaining. Limestone is represented by a blocked surface, as opposite Trenton; *shale*, by fine lining, as opposite Utica and Hudson River; *sandstone* of different degrees of fineness, by dots of different degrees of coarseness; *laminated* or *shaly sandstone*, by cut lines or a combination of short lines and dots, as opposite *Salina* and *Hamilton; conglomerate*, by very coarse or open dots, as opposite Millstone-grit.

2. *Tilted or Folded Rocks.* — In studying a region of tilted rocks it is important that the dip and strike should be obtained *at all outcrops*, and noted down on a map. For the latter, the best mode is to use a symbol like the letter T, giving the top the direction of the strike and the stem that of the dip; and the different angles of dip may be approximately indicated by variations in the length of the stem of the T, as in the annexed figure, in which the ratio of the stem to half the top of the T is for 80° = 1 : 4;



for 70°, 1 : 3; for 60°, 1 : 2; for 50°, 1 : 1⅓; for 45°, 1 : 1; for 35°, 1⅓ : 1; for 25°, 1½ : 1; for 15°, 2 : 1; and for horizontality, a crossed circle.

If, among the exposed sections at a place, none is at right angles to the strike, the dip may be obtained thus: take the dip and the direction along two of the sections; then, from a point, *A*, draw two straight lines, *A B*, *A C*, in the directions of the observed dips, and set off, on each, lengths proportional to the cotangent of its own dip, *A b*, *A c*; then, a line through *b*, *c*, will have the direction of the strike, and a perpendicular to it, that of the dip.

The best *clinometer-compass* has a diameter inside of 3 inches. The square base of the instrument (a very important feature, as stated on page 95) has its sides parallel with the N. S. and E. W. diameters of the compass, and is 3¾ inches on a side. In taking the *strike*, a N. S. side of the base is made to coincide in direction with one of the edges of the outcropping beds in case the exposed surface is horizontal, or with a horizontal line drawn on a surface of one of the beds; but it is best to make the observation *standing*, by holding the instrument between the eye and the rock and obtaining the coincidence by sighting across the N. S. side. The dip may be obtained, with such an instrument, from the under, as well as upper, surface of a projecting ledge, and also from exposed sections scores of yards distant from the observer. (Instruments of this kind are sold in New York by J. & H. J. Green, instrument makers).

3. *Unconformability.* — Never confound the unconformity that is connected with a fault with true unconformability, due to *unconformable superposition*. The different, and differently-dipping, rocks on the opposite sides of a fault of a thousand feet or more *may belong to the same period.*

Never assert with positiveness that unconformability exists, unless the fact is distinctly visible in an actual section showing the *contact of beds of unlike dip;* for the unlike dip in different rocks, if *observed at points only a hundred feet apart*, may be owing to a bend in one or the other stratum in that interval, or to displacement.

Observe the distinction between *overlap* (p. 101), and unconformability due to deposition on upturned strata.

4. *Metamorphic Rocks.* — Study regions of metamorphic or granitoid rocks in precisely the same manner as those of ordinary stratified rocks, whether they be Archæan or of later origin, using lithology in order to follow a series of rocks from mile to mile over a country, but even this with caution, and always looking to stratigraphy and the discovery of fossils for sure testimony as to relative age. Remember also, that a layer of quartzyte *may* be gneiss or mica schist a few rods off; and that the same crystalline rocks, with rare exceptions, may belong to formations of very various geological ages.

As to granite, syenyte, and dioryte, make their age, in each case, a question to be solved by careful stratigraphical investigation. In connection with the investigation the following questions are to be answered: Is the rock *eruptive* granite, syenyte, or dioryte? Is the rock a vein formation? Or, is the rock part of the metamorphic series of a region, as proved by its mode of association with metamorphic rocks, and its gradation into gneissoid granite and gneiss, or into any other schistose crystalline rock? a fact with much the larger part of the granite, syenyte, and dioryte of the world.

5. *Direction of Strike determined without an Instrument in hand.* — It sometimes happens that a geologist is in the field without his compass. His best resource in that case, provided the sun is visible, is the following: Lay a leaf from a note-book over the outcropping rock, with its surface quite level, and one edge (call it A B) in the direction of the strike. Sight the sun across it, or, better, cast the shadow of a plumb-line over it (one made of a blade of grass weighted with a pebble might answer) and draw a line corresponding with the sun's direction thus obtained. The angle between A B and this line (which may be measured with a protractor) is the angle on the horizon between the line of strike and the sun's meridian at the time. On turning, whenever convenient afterward, to a book containing tables of the sun's azimuth, like Albini's "Gli Azimut del Sole," the angular distance of the sun's meridian, from the south point, for the latitude of the place and the time of observation, may be obtained; and from this, the direction of strike is readily derived.

For the convenience of the field geologist a table is here introduced containing the azimuth for the 20th day of each month at the hours from 6 A. M. to 6 P. M., mean time, in the latitudes 38° and 42° : —

		Southeast.							Southwest.					
		VI.	VII.	VIII.	IX.	X.	XI.	Noon.	I.	II.	III.	IV.	V.	VI.
Jan.	Lat. 38°	–	66·3	57·2	46·3	33·6	19·0	2·9 S. E.	13·7	29·0	42·3	53·8	63·6	–
	Lat. 42°	–	67·1	57·0	45·8	33·0	19·0		12·9	27·9	41·3	52·7	63·5	–
Feb.	Lat. 38°	–	74·4	64·6	53·4	39·9	23·6	4·3 S. E.	15·0	32·1	47·0	59·2	69·7	–
	Lat. 42°	–	74·3	63·7	51·9	38·2	22·2		14·0	31·0	45·8	58·4	69·4	–
Mar.	Lat. 38°	91·1	81·5	71·5	60·0	45·2	26·2	3·0 S. E.	20·4	41·0	56·4	69·2	79·3	88·5
	Lat. 42°	91·3	81·2	70·4	58·0	43·1	24·5		19·1	38·5	53·4	66·5	78·4	88·0
April	Lat. 38°	98·7	89·7	80·0	68·1	53·8	30·4	0·4 S. W.	31·2	53·6	68·9	80·7	90·5	99·5
	Lat. 42°	98·4	88·5	77·7	65·3	49·1	27·3		28·0	49·7	65·9	78·3	89·0	98·8
May	Lat. 38°	105·3	97·1	88·0	77·3	62·5	38·1	2·4 S. W.	41·4	64·5	78·5	89·1	98·0	106·3
	Lat. 42°	104·5	95·0	85·0	73·2	57·0	32·6		37·3	59·5	74·9	86·4	96·4	105·8
June	Lat. 38°	108·6	100·5	91·8	81·8	68·5	44·8	0 6 S. E.	44·2	67·7	81·0	90·8	99·6	107·8
	Lat. 42°	108·0	99·0	89·5	78·2	63·0	39·2		38·2	62·5	77·8	89·1	98·7	107·8
July	Lat. 38°	107·7	99·0	89·7	80·0	66·3	44·1	3·8 S. E.	37·1	62·3	77·3	91·0	97·1	105·5
	Lat. 42°	106·7	97·4	87·6	76·2	61·0	38·2		32·3	57·3	73·4	85·5	95·4	104·8
Aug.	Lat. 38°	99·3	91·0	81·0	70·2	54·4	31·6	1·5 S. E.	29·6	52·4	68·1	79·2	90·0	99·0
	Lat. 42°	98·9	90·0	79·4	67·1	51·3	29·6		26·9	49·4	65·8	78·3	89·0	98·9
Sept.	Lat. 38°	90·0	80·0	69·8	57·6	41·7	21·7	2·4 S. W.	26·5	45·7	60·5	72·5	82.7	91·2
	Lat. 42°	89·7	79·4	68·3	55.5	39·5	19·9		24·5	43·2	58·4	70·8	81·7	91·8
Oct.	Lat. 38°	–	70·4	60·	47·5	32·6	14·6	4·6 S. W.	24·0	40·5	54·0	65·2	75·2	–
	Lat. 42°	79·8	69·7	58·6	45·9	31·0	13·8		22·6	38·8	52·5	64·4	74·8	85·3
Nov.	Lat. 38°	–	–	52·9	41·3	27·5	12·4	3·7 S. W.	20·2	34·5	47·2	58·0	–	–
	Lat. 42°	–	63·2	52·7	40·8	27·3	12·2		19·4	33·8	46·6	57·7	67·3	–
Dec.	Lat. 38°	–	–	53·0	42·1	29·5	15·1	0·5 S. W.	16·1	30·4	43·0	54·0	–	–
	Lat. 42°	–	62·9	53·1	41·8	28·9	14·7		15·7	2[illegible]·8	42·5	53·8	63·6	–

INDEX.

NOTE. — An asterisk (*) after the number of a page indicates that there is a reference on the page to a *figure* of the species or object mentioned ; and a section-mark (§) implies that the page contains a *definition*, *explanation*, or *characteristic* of the word or object mentioned.

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EXPLANATION OF PLATES.[1]

PLATE I.

Jurassic Dinosaur, MOROSAURUS GRANDIS Marsh. (One twentieth natural size.) — Page 433.

FIGURE 1. — Fore leg: *s*, scapula; *c*, coracoid; *h*, humerus; *r*, radius; *u*, ulna; *uc*, ulnar carpal; *I*, first metacarpal; *Vmc*, fifth metacarpal.
FIGURE 2. — Hind leg: *il*, ilium; *is*, ischium; *p*, pubis; *f*, femur; *t*, tibia; *f′*, fibula; *a*, astragalus; *c*, calcaneum; *Vmt*, fifth metatarsal.

PLATE II.

Jurassic Dinosaurs of the genus APATOSAURUS of Marsh. — Page 433.

FIGURE 1. — Cervical vertebra of the APATOSAURUS LATICOLLIS Marsh, back view (one sixteenth natural size): *c*, posterior articular surface or cup; *d*, diapophysis; *p*, parapophysis; *h*, hatchet bone, or anchylosed rib; *z′*, postzygapophysis; *f′*, lateral foramen.
FIGURE 2. — Side view of same vertebra: *b*, anterior articular surface; *c*, posterior id.; *f*, foramen in centrum; *z*, prezygapophysis; *z′*, postzygapophysis.
FIGURE 3. — Sacrum of the Dinosaur, APATOSAURUS AJAX Marsh (one tenth natural size): *a*, anterior face of first sacral vertebra; *p*, posterior face of last sacral vertebra; *b*, transverse process of first sacral vertebra; *c*, transverse process of second; *d*, transverse process of third; *ff′*, foramina between transverse processes; *e e′*, surfaces for union with ilia.

PLATE III.

Jurassic Dinosaurs, LAOSAURIDÆ of Marsh. — Page 433.

FIGURES 1, 2. — Tooth of LAOSAURUS ALTUS Marsh: front and side view (twice natural size).
FIGURE 3. — Hind leg of same (one eighth natural size): letters as in Plate I.

[1] For the following twelve plates this work is indebted to Prof. O. C. Marsh.

FIGURE 4. — Pelvis of CAMPTONOTUS DISPAR Marsh (one twelfth natural size) : *a*, acetabulum ; other letters as in Figure 5.

FIGURE 5. — Hind leg of same (one twelfth natural size : letters as in Plate I.

FIGURE 6. — Fore leg of same (one twelfth natural size).

PLATE IV.

Cretaceous Bird, HESPERORNIS REGALIS Marsh. — Page 466.

FIGURE 1. — Restoration of skeleton (one eighth natural size).

FIGURE 2. — Left lower jaw : top view (one half natural size).

FIGURE 3. — The same : side view.

FIGURE 4. — Tooth (four times natural size).

FIGURE 5. — Twentieth vertebra, dorsal : side view (one half natural size).

FIGURE 6. — The same : front view.

FIGURE 7. — Pelvis : side view (one fifth natural size) ; *a*, acetabulum ; *il*, ilium ; *is*, ischium ; *p*, pubis ; *p′*, post-pubis.

PLATE V.

Cretaceous Bird, ICHTHYORNIS of Marsh. — Page 466.

FIGURE 1. — Restoration of ICHTHYORNIS VICTOR Marsh (one half natural size).

FIGURE 2. — Left lower jaw of ICHTHYORNIS DISPAR Marsh : side view (twice natural size).

FIGURE 3. — The same : top view.

FIGURE 4. — Cervical vertebra of ICHTHYORNIS DISPAR Marsh : side view (twice natural size).

FIGURE 5. — The same : front view.

PLATE VI.

Eocene Mammal, CORYPHODON of Owen. — Page 502.

FIGURE 1. — Outline of skull and brain-cavity of CORYPHODON HAMATUS Marsh : top view. About one fifth natural size.

FIGURE 2. — Cast of brain-cavity of CORYPHODON HAMATUS : top view (one half natural size).

FIGURE 3. — Left fore foot of CORYPHODON (one third natural size).

FIGURE 4. — Left hind foot of CORYPHODON (one third natural size).

PLATE VII.

Eocene Mammal, DINOCERAS of Marsh. — Page 503.

FIGURE 1. — Outline of skull and brain-cavity of DINOCERAS MIRABILE Marsh: top view (one eighth natural size).

FIGURE 2. — Skull and lower jaw of DINOCERAS (one eighth natural size).

FIGURE 3. — Left fore foot of DINOCERAS (one fifth natural size).

FIGURE 4. — Left hind foot of DINOCERAS (one fifth natural size).

PLATE VIII.

Eocene Mammals, TILLODONTIA of Marsh. — Page 503.

FIGURE 1. — Outline of skull and brain-cavity of TILLOTHERIUM FODIENS Marsh: top view (one fourth natural size).

FIGURE 2. — Skull and lower jaw of TILLOTHERIUM FODIENS (one fourth natural size): *a*, upper incisor; *b*, lower incisor; *c*, condyle.

FIGURE 3. — Last upper molar of TILLOTHERIUM LATIDENS Marsh. Natural size.

FIGURE 4. — Lower molar of ANCHIPPODUS MINOR Marsh. Natural size.

FIGURE 5. — Ungual phalanx of TILLOTHERIUM FODIENS Marsh: *a*, front view; *b*, side view. Natural size.

PLATE IX.

Miocene Mammals, BRONTOTHERIUM of Marsh. — Page 504.

FIGURE 1. — Side view of skull of BRONTOTHERIUM INGENS Marsh (one twelfth natural size).

FIGURE 2. — Top view of skull (one twelfth natural size).

FIGURE 3. — Right fore foot (one sixth natural size).

FIGURE 4. — Right hind foot (one sixth natural size).

PLATE X.

Successive forms of the HORSE TYPE, from Marsh. — Page 507.

COLUMN 1. — Fore feet.

COLUMN 2. — Hind feet.

COLUMN 3. — Fore-arms, or radii and ulnæ, showing the change in the latter and the soldering of the bone at last closely to the radius.
COLUMN 4. — Legs, or tibiæ and fibulæ.
COLUMN 5. — Side view of upper molars.
COLUMN 6. — Crowns of upper molars.
COLUMN 7. — Crowns of lower molars.

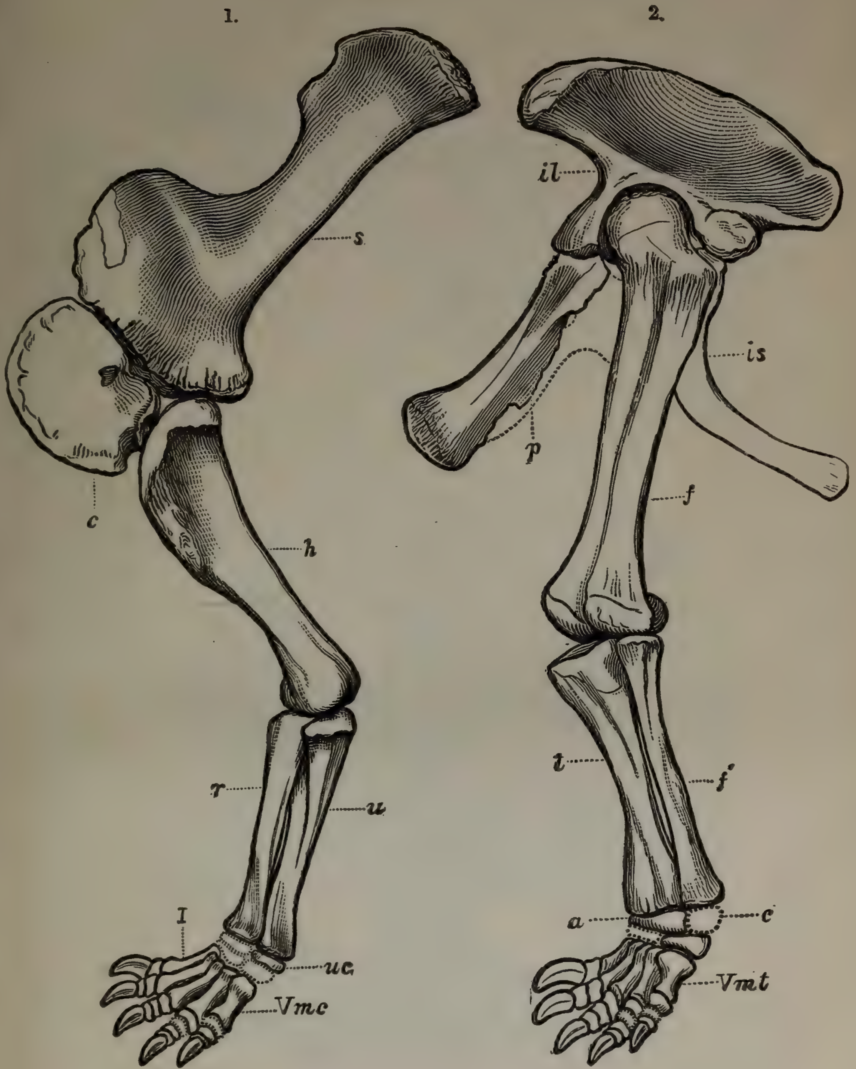
PLATE XI.

Illustrations of Brain-growth during the Cenozoic, after Marsh. — Page 508.

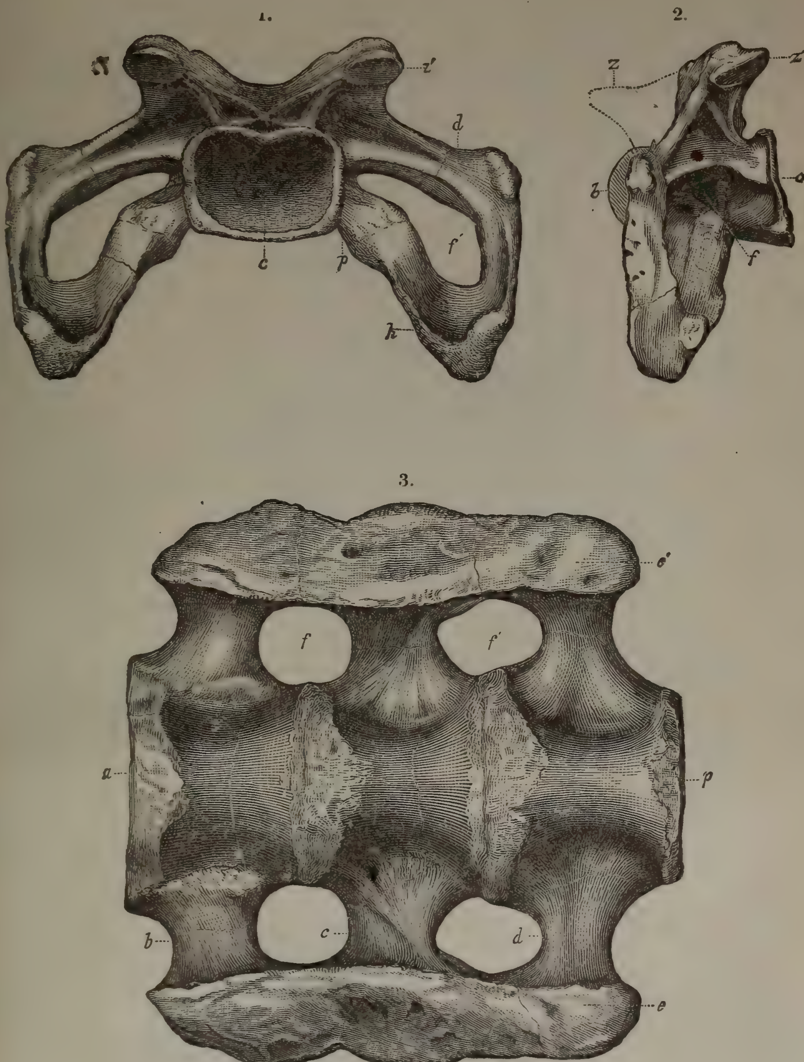
FIGURE 1. — Outline of skull and brain-cavity of DINOCERAS (Eocene).
FIGURE 2. — Outline of skull and brain-cavity of BRONTOTHERIUM (Miocene).
FIGURE 3. — Outline of skull and brain-cavity of the HORSE (Recent).

PLATE XII.

Diagram of Strata, arranged by Marsh, to show the succession in Vertebrate Life in America.

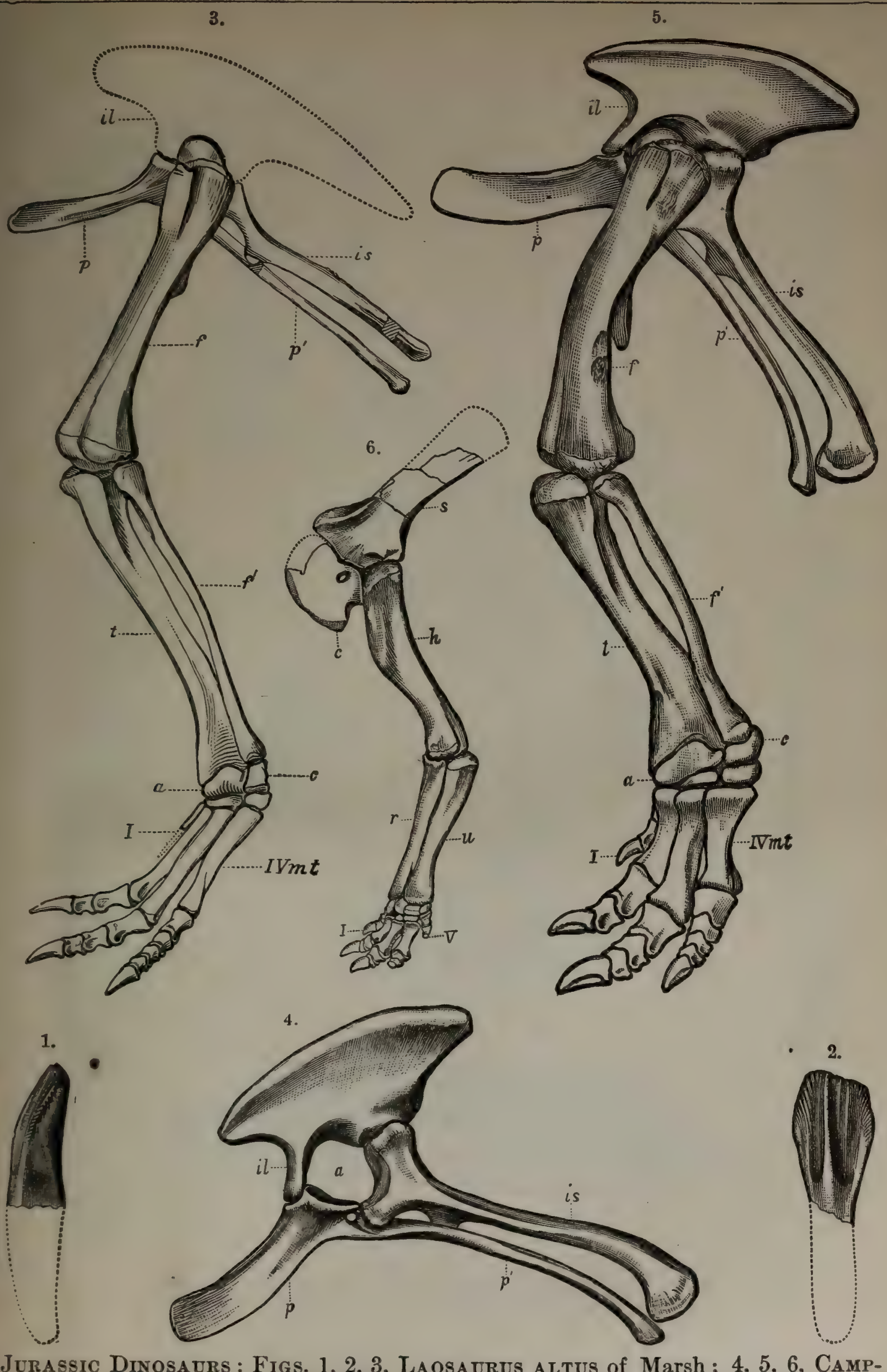


JURASSIC DINOSAUR: MOROSAURUS GRANDIS of Marsh.
Fig. 1, fore leg; 2, hind leg. One twentieth natural size.



JURASSIC DINOSAUR: APATOSAURUS of Marsh.

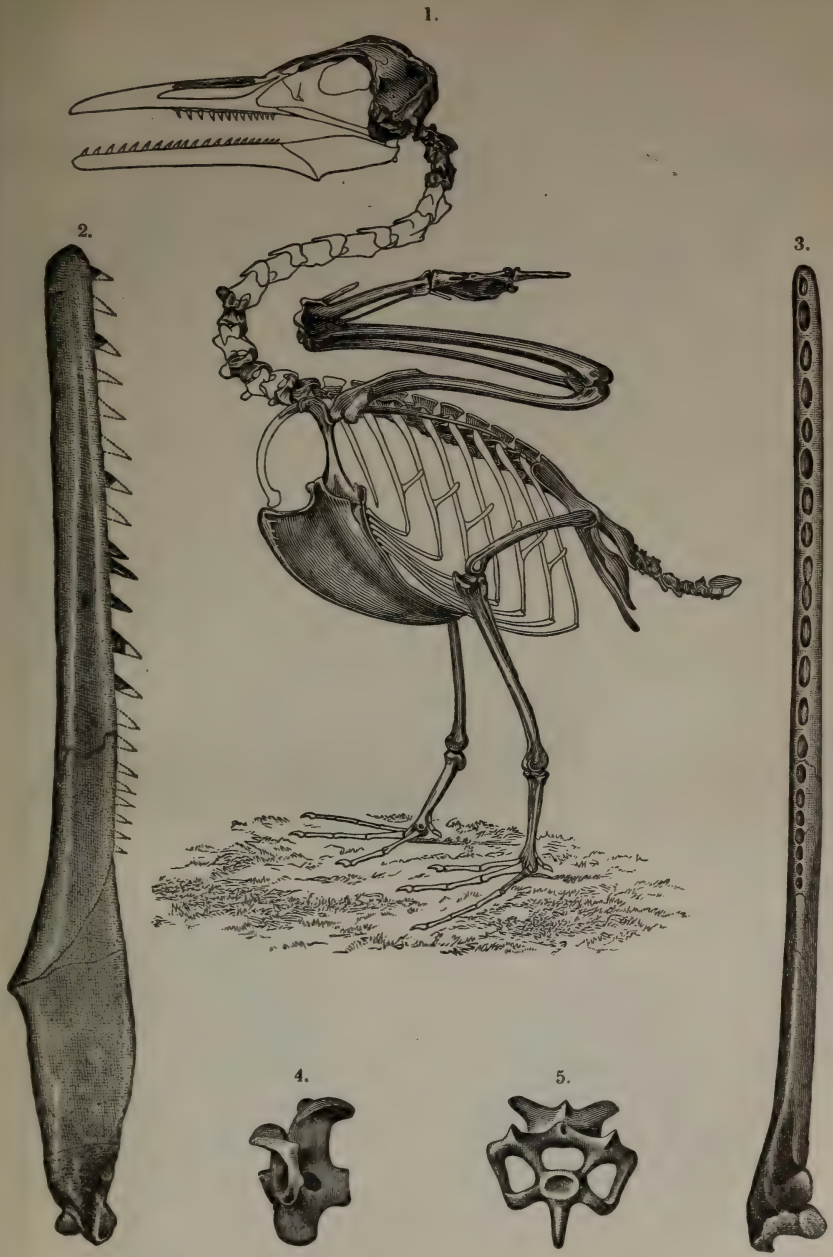
Cervical vertebra ($\times \frac{1}{16}$) and Sacrum ($\times \frac{1}{10}$).



JURASSIC DINOSAURS: FIGS. 1, 2, 3, LAOSAURUS ALTUS of Marsh; 4, 5, 6, CAMPTONOTUS DISPAR of Marsh.

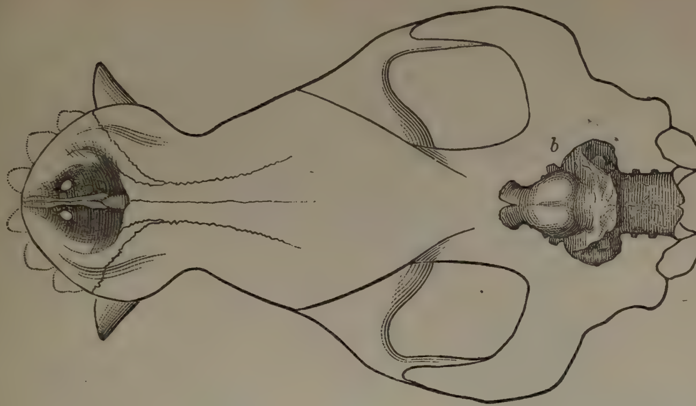
CRETACEOUS BIRD: HESPERORNIS REGALIS of Marsh.

PLATE V.

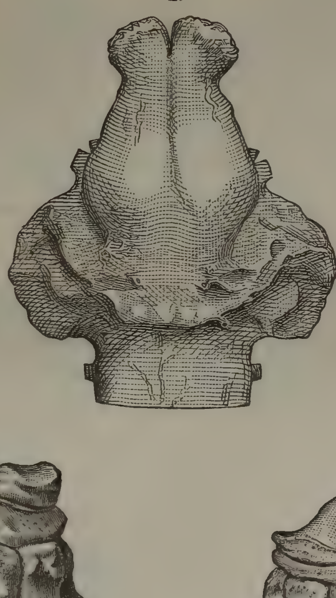


CRETACEOUS BIRDS: Fig. 1, ICHTHYORNIS VICTOR of Marsh; 2–5, I. DISPAR of Marsh.

1.



2.

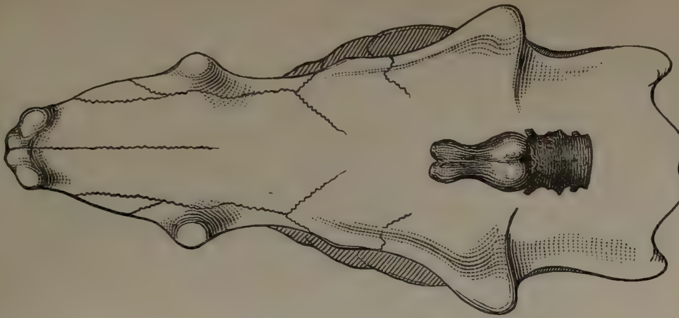


3.

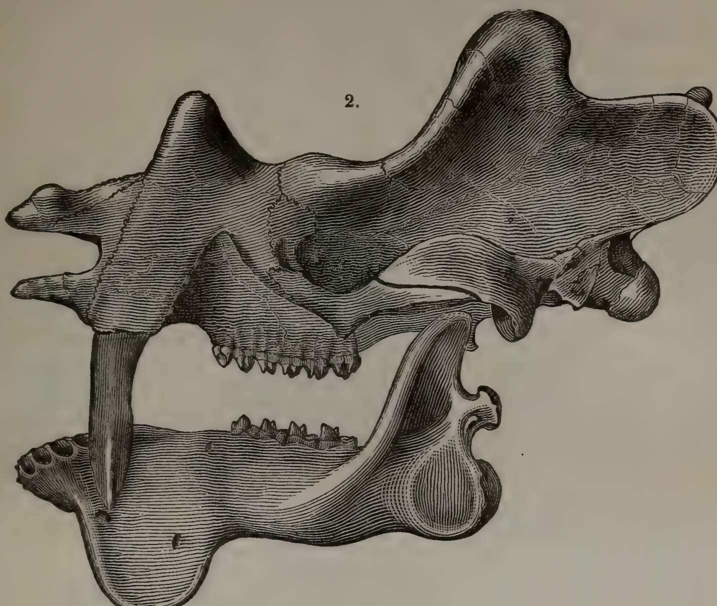
4

Eocene Mammal: Coryphodon hamatus of Marsh.
Figs. 1, 2, skull and brain; 3, 4, fore and hind feet.

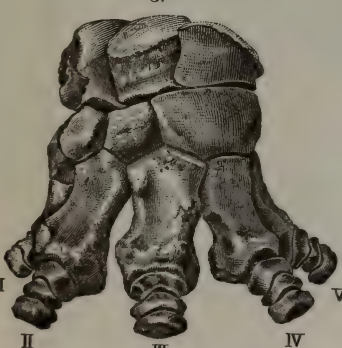
1.



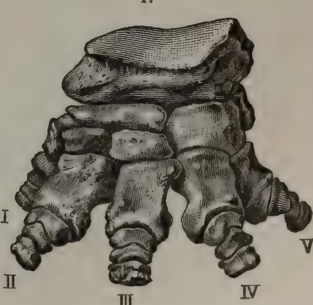
2.



3.

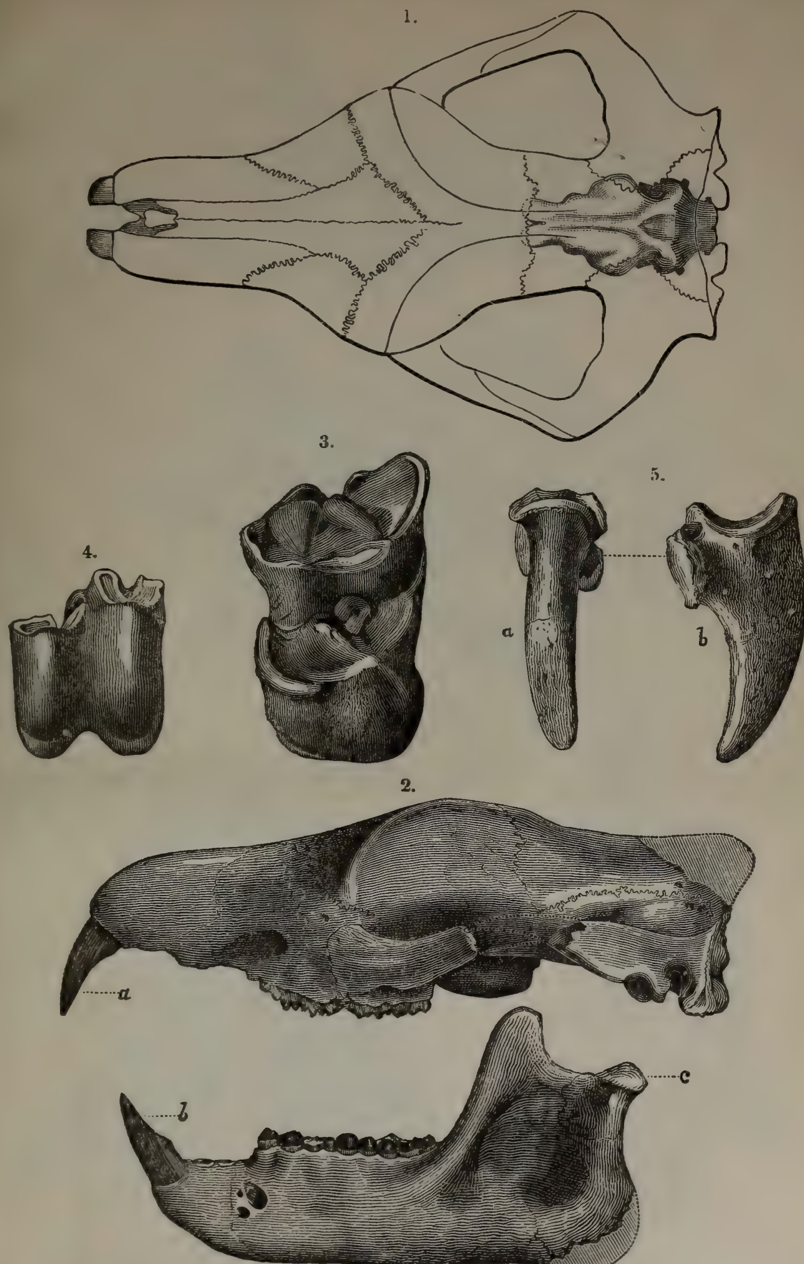


4.



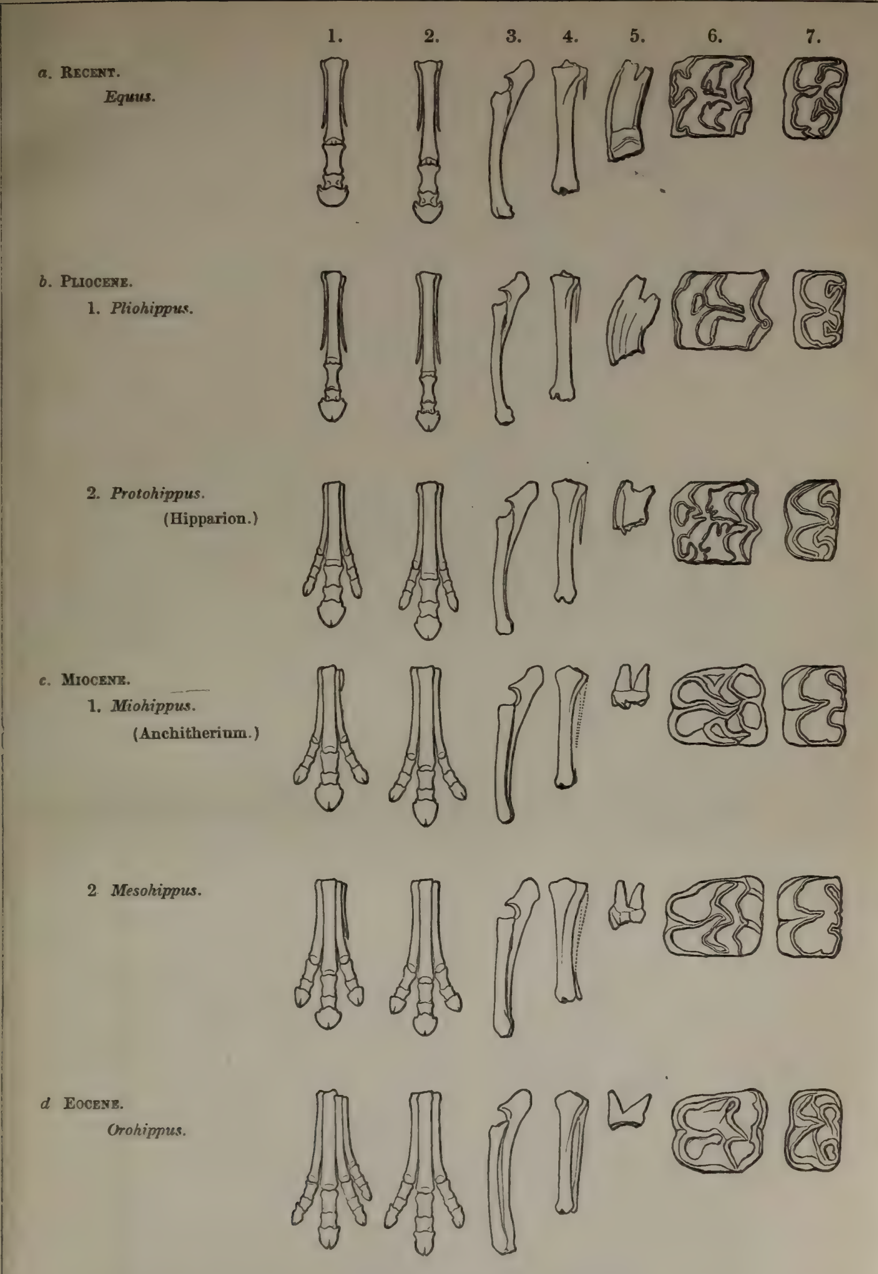
Eocene Mammal: Dinoceras of Marsh.

Figs. 1, 2, skull and brain ($\times \frac{1}{8}$); 3, 4, fore and hind feet ($\times \frac{1}{5}$).



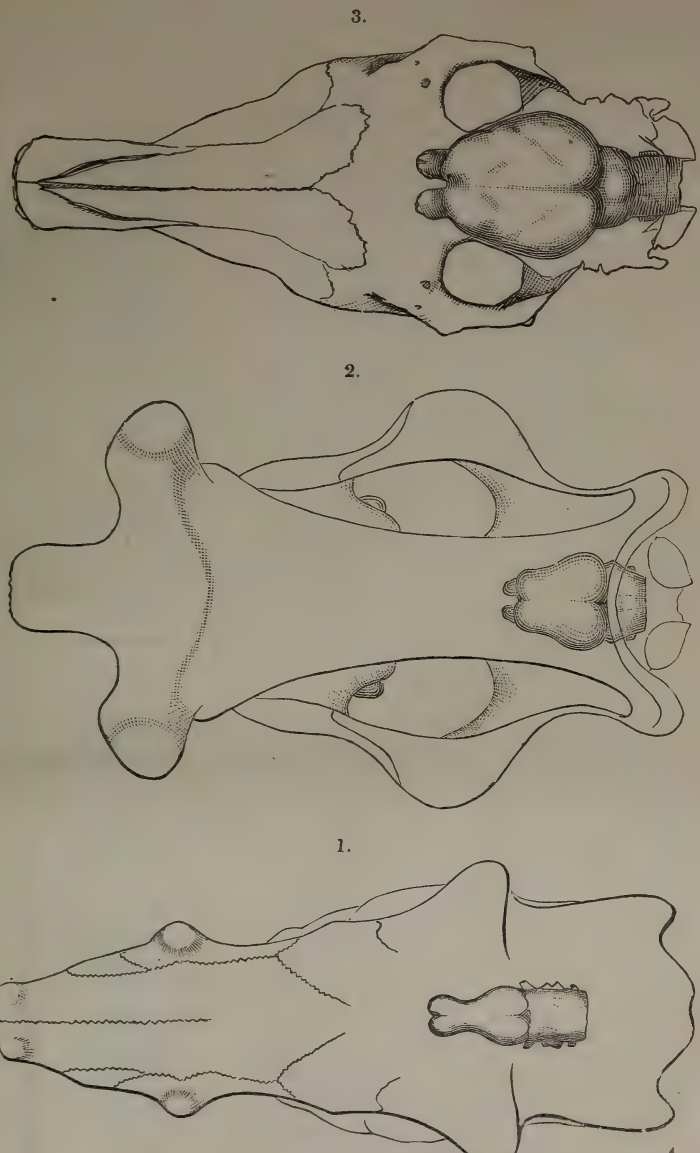
EOCENE MAMMALS: TILLODONTIA of Marsh.
Figs. 1, 2, skull and brain; 3. 4. upper and lower molars; 5, ungual phalanx.

MIOCENE MAMMAL: BRONTOTHERIUM of Marsh.
Figs. 1, 2, skull ($\times \frac{1}{12}$); 3, 4, fore and hind feet.



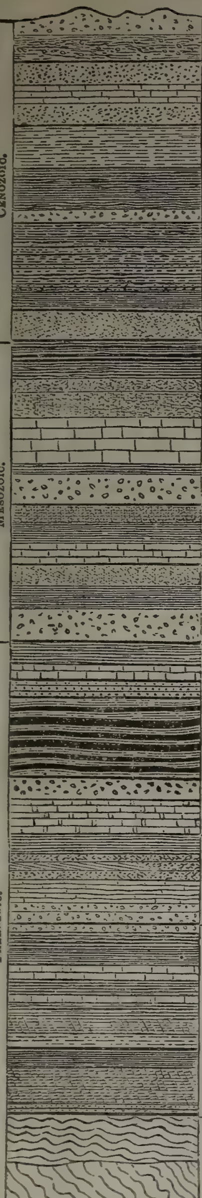
ILLUSTRATIONS OF THE CHARACTERS OF SUCCESSIVE GENERA UNDER THE HORSE TYPE. (From Marsh.)

PLATE XI.



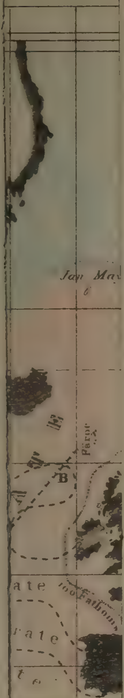
ILLUSTRATIONS OF THE SIZES OF BRAINS IN SUCCESSIVE GENERA OF UNGULATES.

Fig. 1, DINOCERAS (Eocene); 2, BRONTOTHERIUM (Miocene); 3, Modern HORSE. (From Marsh.)



Cenozoic.	Recent. Quaternary.			Tapir, Peccary, Bison, Llama. *Equus.* *Megatherium*, *Mylodon*.
	Tertiary.	Pliocene.	Equus Beds.	*Equus*, *Tapirus*. *Elephas*.
			Pliohippus Beds.	*Pliohippus*, *Tapiravus*, *Mastodon*. *Protohippus*, *Aceratherium*, *Bos*.
		Miocene.	Miohippus Beds.	*Miohippus*, *Diceratherium*, *Thinohyus*.
			Oreodon Beds.	Edentates, *Moropus*. *Hyænodon*, *Eporeodon*, *Hyracodon*.
			Brontotherium Beds.	*Mesohippus*, *Menodus*, *Elotherium*.
		Eocene.	Diplacodon Beds.	*Epihippus*, *Amynodon*.
			Dinoceras Beds.	*Tinoceras*, *Uintatherium*, *Limnohyus*, *Orohippus*, *Helaletes*, *Colonoceras*.
			(Green River Beds.)	
			Coryphodon Beds.	*Eohippus*, Monkeys, Carnivores, Ungulates, Tillodonts, Rodents, Serpents.
Mesozoic.	Cretaceous.		Lignite Series.	*Hadrosaurus*, *Dryptosaurus*.
			Pteranodon Beds.	Birds with Teeth (*Odontornithes*,) *Hesperornis*, *Ichthyornis*, *Apatornis*. Mosasaurs, *Edestosaurus*, *Lestosaurus*, *Tylosaurus*. Pterodactyls, Plesiosaurs.
			Dakota Group.	
	Jurassic.		Atlantosaurus Beds. Sauranodon Beds.	Dinosaurs, *Morosaurus*, *Apatosaurus*, *Laosaurus*. *Nanosaurus*. Turtles. *Diplosaurus*. Mammals, *Dryolestes*, *Stylacodon*, *Tinodon*.
	Triassic.		Conn. River Beds.	First Mammals (Marsupials), *Dromatherium*. Dinosaur Footprints, *Amphisaurus*. Crocodiles, *Belodon*.
Paleozoic.	Carboniferous.		Permian.	Reptiles, *Nothodon*, *Sphenacodon*.
			Coal Measures.	First Reptiles (?)
			Subcarboniferous.	First known Amphibians (Labyrinthodonts).
	Devonian.		Upper Devonian. Corniferous. Schoharie Grit.	First known Fishes.
	Silurian.		Upper Silurian. Lower Silurian.	No Vertebrates known.
	Archæan.		Huronian. Laurentian.	

DIAGRAM OF STRATA TO ILLUSTRATE VERTEBRATE LIFE IN AMERICA.
(After Marsh.)


B
ate
100 Fathoms
rate

PHYSIOGRAPHIC CHART
OF
THE WORLD
BY
JAMES D. DANA.
Equatorial Scale = 1: 130,000,000.
Light shading of the land indicates a height under 800 feet
Dark shading of the land indicates a height above 800 feet
Greenland
Hudson Bay
Sea of Okhotsk
S. FRIGID
N. FRIGID
Sub Frigid
Cold Temperate
Sub Temperate
Temperate
Warm Temperate
Sub Torrid
Super Torrid
Antarctic Circle
90 Long. W. Greenwich 60
60 Long. E. Greenwich 90